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EPA ALKALI SCRUBBING TEST FACILITY: ADVANCED PROGRAM

Michael Epstein

Bechtel Corporation

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Industrial Environmental Research Laboratory

September 1975

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The report gives results of advanced program tests on a prototype lime/limestone wet-scrubbing SO_2 and particulate removal facility at TVA's Shawnee Power Station. With the objective of achieving reliable mist eliminator operation, a venturi/spray tower was operated with lime slurry, and a Turbulent Contact Absorber (TCA) with limestone. Each had 30,000 acfm (10MW equivalent) flue gas capacity. The venturi/spray tower system was maintained essentially clean in an 823-hour run at 8.0 ft/sec gas velocity and 8% slurry solids (the 3-pass, open-vane chevron mist eliminator was intermittently washed on both topside and underside with makeup water). The TCA system was operated successfully in an 1835-hour run at 8.6 ft/sec gas velocity and 15% slurry solids (the mist elimination system consisted of a Koch Flexitray in series with a 6-pass, closed-vane chevron mist eliminator, both with underside wash). Both scrubber systems operated with better than 99% particulate removal efficiency and with outlet grain loadings of 0.01 to 0.03 grains/scf. A correlating equation is presented for TCA pressure drop tests.

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Limestone	Prototypes	Particulates		
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ADVANCED PROGRAM

First Progress Report

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Prepared for

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ABSTRACT

This report presents the results of advanced program testing performed from October 1974 through April 1975 on a prototype lime/limestone wet-scrubbing test facility for removing SO_2 and particulates from coal-fired boiler flue gases. The test facility is located at TVA's Shawnee Power Station, Paducah, Kentucky. Tests were conducted on two parallel scrubber systems, a venturi/spray tower in lime service and a Turbulent Contact Absorber (TCA) in limestone service, each with a 30,000 acfm (10 Mw equivalent) flue gas capacity. The primary objective was to achieve reliable operation of the mist eliminators.

The venturi/spray tower system was maintained essentially clean in an 823-hour run in lime service at 8.0 ft/sec superficial gas velocity and 8 percent slurry solids concentration. In this run the 3-pass, open-vane chevron mist eliminator was intermittently washed on both topside and underside with makeup water.

The TCA system was operated successfully in an 1835-hour run in limestone service at 8.6 ft/sec superficial gas velocity and 15 percent slurry solids concentration. The TCA mist elimination unit consisted of a Koch Flexitray in series with a 6-pass, closed-vane chevron mist eliminator, both with underside wash.

Both scrubber systems operated with better than 99 percent particulate removal efficiency and with outlet grain loadings of 0.01 to 0.03 grains/scf. Pressure drop tests were made on the TCA and a correlating equation is presented.

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CONTENTS

Section			Page
1	SUMMARY		1-1
	1.1	Venturi/Spray Tower Lime Reliability Test Results	1-3
	1.2	TCA Limestone Reliability Test Results	1-4
	1.3	Operating Experience	1-6
	1.4	Particulate Removal Test Results	1-10
	1.5	TCA Pressure Drop Data	1-10
2	INTRODUCTION		2-1
3	TEST FACILITY		3-1
	3.1	Scrubber Selection	3-1
	3.2	System Description	3-6
	3.3	EPA Pilot Plant Support	3-9
4	TEST PROGRAM		4-1
	4.1	Test Program Objectives and Schedule	4-1
	4.2	Closed Liquor Loop Operation	4-3
	4.3	Analytical Program	4-5
	4.4	Data Acquisition and Processing	4-7
5	VENTURI/SPRAY TOWER LIME RELIABILITY TEST RESULTS		5-1
	5.1	Performance Data and Test Evaluation	5-1
	5.2	Material Balances	5-19
	5.3	Conclusions	5-21
6	TCA LIMESTONE RELIABILITY TEST RESULTS		6-1
	6.1	Performance Data and Test Evaluation	6-1
	6.2	Material Balances	6-23
	6.3	Conclusions	6-25

Section | Page

7 OPERATING EXPERIENCE DURING LIME/LIMESTONE TESTING 7-1
- 7.1 Mist Elimination Systems 7-1
- 7.2 Scrubber Internals 7-3
- 7.3 Hot-Gas/Liquid Interface 7-5
- 7.4 Reheaters 7-6
- 7.5 Fans 7-7
- 7.6 Pumps 7-7
- 7.7 Waste Solids Handling 7-8
- 7.8 Alkali Addition Systems 7-9
- 7.9 Instrument Operating Experience 7-11
- 7.10 Lining Materials 7-12

8 PARTICULATE REMOVAL TEST RESULTS 8-1

9 ANALYSIS OF TCA PRESSURE DROP DATA 9-1

10 REFERENCES 10-1

Appendices		Page
A	Converting Units of Measure	A-1
B	Scrubber Operating Periods	B-1
C	Properties of Raw Materials	C-1
D	Graphical Operating Data from Venturi/Spray Tower Lime Reliability Tests	D-1
E	Average Liquor Compositions for Venturi/Spray Tower Lime Reliability Tests	E-1
F	Graphical Operating Data from TCA Limestone Reliability Tests	F-1
G	Average Liquor Compositions for TCA Limestone Reliability Tests	G-1
H	Definition of Statistical Terms	H-1

ILLUSTRATIONS

Figure		Page
3-1	Schematic of Venturi Scrubber and Spray Tower	3-3
3-2	Schematic of Three-Bed TCA Scrubber	3-4
3-3	Test Facility Mist Eliminator Configurations	3-5
3-4	Typical Process Flow Diagram for Venturi/Spray Tower System	3-7
3-5	Typical Process Flow Diagram for TCA System	3-8
4-1	Shawnee Advanced Test Schedule	4-4
9-1	Pressure Drop Across the Four-Grid TCA Without Spheres	9-3
9-2	Pressure Drop Across the Four-Grid, Three-Bed TCA with Five Inches of HDPE Spheres per Bed	9-4
9-3	Pressure Drop Across the Four-Grid, Three-Bed TCA with Five Inches of TPR Spheres per Bed	9-5
9-4	Pressure Drop Across the Four-Grid, Three-Bed TCA with Seven and One-Half Inches of TPR Spheres per Bed	9-6
9-5	Comparison of Experimental Data and Predicted Values of Pressure Drop for the Four-Grid, Three-Bed TCA	9-7

TABLES

Table		Page
4-1	Field Methods for Batch Chemical Analysis of Slurry and Alkali Samples	4-5
5-1	Summary of Lime Reliability Tests on Venturi/Spray Tower System	5-2
5-2	Summary of Material Balances for Sulfur and Calcium from Lime Reliability Tests	5-20
6-1	Summary of Limestone Reliability Tests on TCA System	6-2
6-2	Summary of Material Balances for Sulfur and Calcium from Limestone Reliability Tests	6-24
8-1	Overall Particulate Removal in Venturi/Spray Tower During Lime Reliability Tests	8-2
8-2	Overall Particulate Removal in TCA Scrubber During Limestone Reliability Tests	8-3

Section 1

SUMMARY

This is the initial report on an advanced test program conducted by the Environmental Protection Agency (EPA) to test prototype lime and limestone wet-scrubbing systems for removing sulfur dioxide and particulate matter from coal-fired boiler flue gases. It covers the period from October 1974 through April 1975. Results of an earlier test program have been reported in EPA-650/2-75-047. The program is being conducted in a test facility integrated into the flue gas ductwork of boiler No. 10 at the Tennessee Valley Authority (TVA) Shawnee Power Station, Paducah, Kentucky. Bechtel Corporation of San Francisco is the major contractor and test director, and TVA is the constructor and facility operator.

There are two parallel scrubbing systems being operated during the advanced test program:

- A venturi followed by a spray tower
- A Turbulent Contact Absorber (TCA)

Each system is capable of treating approximately 10 Mw equivalent (30,000 acfm* @ 300°F) of flue gas containing 1500 to 4500 ppm sulfur

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*Although it is the policy of the EPA to use the Metric System for quantitative descriptions, the British System is used in this report. Readers who are more accustomed to metric units are referred to the conversion table in Appendix A.

dioxide and 2 to 4 grains/scf of particulates. During this reporting period, the venturi/spray tower has operated on lime and the TCA on limestone.

Objectives during the advanced test program are:

- To continue long-term testing with emphasis on operation of mist elimination systems.
- To investigate advanced process and equipment design variations for improving system reliability and economics.
- To evaluate ways of increasing limestone utilization, improving waste solids separation, and reducing waste sludge production.
- To evaluate variable load scrubber operation.
- To evaluate existing technology for producing a waste sludge with improved properties.
- To evaluate system performance and reliability without fly ash in the flue gas.
- To determine practical upper limits of SO_2 removal efficiency.
- To evaluate the TCA with lime and the venturi/spray tower with limestone.
- To characterize stack gas emission.
- To evaluate, under the direction of TVA, corrosion and wear of equipment components and materials.
- To develop a computer program, in conjunction with TVA, for the design and cost comparison of full-scale lime and limestone systems.

1.1 VENTURI/SPRAY TOWER LIME RELIABILITY TEST RESULTS

Lime reliability tests were conducted on the adjustable throat venturi scrubber followed by a 4-header spray tower. The spray tower had a 3-pass, open-vane chevron mist eliminator with provision for both underside and topside intermittent washing.

Scale-free operation with a clean mist elimination system was achieved in an 823 hour run under the following conditions (Run 624-1A):

Spray tower gas velocity	8.0 ft/sec
Venturi liquid-to-gas/ratio	25 gal/mcf
Spray tower liquid-to-gas ratio	50 gal/mcf
Percent solids recirculated	8
Effluent residence time	17 minutes
Scrubber inlet slurry pH (controlled)	8.0

SO_2 removal was 70 to 87 percent at an inlet SO_2 concentration range of 2250 to 3750 ppm, lime utilization was 90 percent, and total pressure drop was 13 inches H_2O including the mist elimination system and 9 inches H_2O across the venturi. Scale-free operation was expected because the sulfate (gypsum) saturation of the scrubber effluent liquor was 120 percent. Earlier tests have shown that sulfate scale is a significant problem only if sulfate saturation exceeds about 135 percent.

During Run 624-1A, the mist eliminator was kept clean by a combination of intermittent underside wash and sequential topside wash, both with makeup water. The underside wash rate was 3 gpm/ft^2 at 45 psig for 8 minutes every 4 hours. The topside wash was accomplished by operating 6 nozzles in sequence. Every 80 minutes, one nozzle was activated for 4 minutes at a rate of 0.5 gpm/ft^2 at 13 psig.

A 4-pass, closed-vane, cone-shaped chevron mist eliminator was tested during 4 runs (611-1A, 618-1A, 619-1A, and 621-1A), but it continually plugged and further tests will not be made.

Tests have shown that sulfate saturation, and thus potential for sulfate scale, can be reduced by:

- Increasing scrubber slurry solids concentration (Run 603-1A versus 601-1A).
- Increasing effluent residence time (Run 622-1A versus 619-1A).
- Adding makeup lime to the scrubber downcomer rather than to the effluent hold tank (Run 609-1A versus 610-1A).

Run 611-1A has demonstrated that the scrubber can operate unsaturated with respect to sulfate by adding magnesium ion (MgO) to the circulating slurry. Gypsum scale from previous operation dissolved during this run.

1.2 TCA LIMESTONE RELIBILITY TEST RESULTS

The TCA scrubber was operated with 3 beds of 1 1/2-inch, 5-gram spheres, each 5 inches deep. The mist elimination system consisted of a 6-pass, closed-vane chevron mist eliminator preceded by a Koch Flexitray used as a wash tray.

Reliable operation of the TCA and its mist elimination system in limestone slurry service was demonstrated during Runs 535-2A and 535-2B, which continued for 2325 hours without cleaning the mist eliminator.

Test conditions were:

TCA gas velocity	8.6 ft/sec
Liquid-to-gas ratio	73 gal/mcf
Percent solids recirculated	15
Effluent residence time	15 minutes
Percent SO_2 removal (controlled)	84

Inlet SO_2 concentration ranged from 2000 to 4000 ppm, scrubber inlet liquor pH ranged from 5.7 to 6.1, limestone utilization was 65 percent, and total pressure drop was 6 to 7 inches including the mist elimination system. Sulfate saturation of the scrubber exit liquor averaged 110 percent. This is below the level of 135 percent predicted from earlier tests as being the point above which sulfate scale is a significant problem.

In Run 535-2A, the mist eliminator was washed continuously on the underside at 0.3 gpm/ft^2 (15 gpm) with a mixture of process liquor and makeup water containing 40 percent process liquor. The Koch tray was fed with the mist eliminator wash plus 9 gpm clarified liquor. The underside of the Koch tray was sparged with 125 psig steam for 1 minute each hour.

Solids buildup on the walls between the Koch tray and the slurry spray nozzles, which had been a problem in Run 535-2A and previous runs was eliminated during Run 535-2B by replacing the steam sparger with a single-nozzle underspray using Koch tray effluent. The underspray had sufficiently wide coverage to flush both the Koch tray and the adjacent walls.

In subsequent runs at higher scrubber gas velocities, soft solids tended to build up on the chevron mist eliminator. In Run 538-2A at 10 ft/sec, the mist eliminator was 8 percent restricted after 562 operating hours. In Run 539-2A at 12 ft/sec, the mist eliminator was 11 percent restricted after 215 hours.

During Run 539-2A, the scrubber recirculation liquor was unexpectedly low in sulfate concentration (only 25 percent of saturation), and sulfite scaling occurred on most scrubber surfaces below the Koch tray. A series of exploritory runs indicated that these conditions were probably caused by a relatively high scrubber liquor pH (~6.0 at the scrubber inlet) and a relatively low liquid-to-gas ratio (43 gal/mcf). Liquid-to-gas ratio in this run was limited by flooding at the 12 ft/sec gas velocity. The causes for unsaturated operation during Run 539-2A are being further investigated at the EPA pilot facility in Research Triangle Park, North Carolina.

1.3 OPERATING EXPERIENCE

Mist elimination systems have already been discussed. This section covers other aspects of scrubber system operations.

1.3.1 Scrubber Internals

The 5-gram thermoplastic rubber (TPR) spheres used in the TCA had a weight loss of only 11.5 percent in 3784 hours of service (2757 hours at 8.6 ft/sec and 1027 hours at 10 ft/sec gas velocity). Five-gram high-density polyethylene (HDPE) spheres failed after about 1100 hours of service (800 hours at 12 ft/sec and 300 hours at 8.6 ft/sec gas velocity).

The 316 stainless steel bar-grids in the TCA have shown no evidence of erosion after 9000 hours of operation. The 316 stainless steel slurry spray nozzles, operating with 15 percent slurry solids at 5 psi pressure drop, have shown no evidence of erosion after 4500 hours of operation.

In the spray tower, stellite tips on the spray nozzles have shown negligible wear after 7200 hours of slurry service at 10 psi pressure drop and 8 percent slurry solids. A 15 percent weight loss has been observed, however, in the 316 stainless steel nozzle bases.

Some erosion and stress cracking has been observed in the venturi scrubber. Successful repairs have been made by welding the cracks and covering eroded areas with neoprene rubber.

1.3.2 Hot-Gas/Liquid Interface

The TCA flue gas cooling system consists of 3 slurry spray nozzles in the flue gas inlet duct and a soot blower. Soot blowing frequency was successfully reduced during this reporting period from once every 4 hours to once a day.

1.3.3 Reheaters

The reheater on the venturi/spray tower includes a fuel-oil-fired external combustion chamber. This unit has operated with few problems for over 7000 hours. The inlined-fired reheater on the TCA was modified during the May 1975 boiler outage to incorporate an external combustion chamber.

1.3.4 Fans

No significant problems occurred with fans during the current reporting period.

1.3.5 Pumps

Frequent packing failure has been a problem on 50 to 100 gpm rubber-lined centfigugal pumps in slurry service. Adequate purge air cannot be maintained on the air flushed seals without vapor locking the pumps. Failures have been less frequent on larger pumps because the purge air volume is small compared with the pump capacity. A mechanical seal is scheduled for testing on the smaller pumps.

Moyno pumps for feeding 60 wt % limestone slurry are purposely oversized and allowed to wear until flow can no longer be maintained. Typical operating life has been 2000 hours for a rotor and 1000 hours for a stator.

1.3.6 Waste Solids Handling

The Maxibelt rotary drum vacuum filter was converted to a single roll type with air blowback and scraper discharge in February 1975. With the new arrangement operating experience has been too limited to predict accurate cloth life.

The centrifuge was operated intermittently for 1745 hours during the current reporting period. Significant wear was noted during the May 1975 boiler outage but no repairs were made.

The TCA clarifier was overloaded at times during scrubber operation at 12 ft/sec gas velocity. The feed well was extended during the May 1975 boiler outage to improve overflow clarity.

1.3.7 Alkali Addition Systems

The lime addition system has operated reliably for over 9000 hours. After modifications early in the program, the limestone addition system has given satisfactory service for almost 7000 operating hours.

1.3.8 Instruments

A continuous ultrasonic cleaner has been used successfully to reduce scale buildup to routine weekly cleaning on a submersible pH probe in slurry service.

Several failures have been experienced with Scothane and Adiprene-L linings in 1 1/2-inch magnetic flowmeters. No difficulties have been experienced with larger meters lined with neoprene or smaller meters lined with Teflon. The 1 12/-inch flowmeters will be relined with Teflon.

1.3.9 Lining Materials

Both neoprene rubber and Flakeline 103 linings have shown excellent resistence to erosion and deterioration. Epoxylite-203 has been used successfully for lining repairs.

1.4 PARTICULATE REMOVAL TEST RESULTS

Overall particulate removal efficiencies were measured periodically during the lime/limestone reliability testing. For the venturi/spray tower system, particulate removals of 99.0 to 99.3 percent were obtained with outlet grain loadings ranging from 0.015 to 0.024 grains/scf.

For the TCA system, particulate removals ranged from 99.0 to 99.7 with outlet grain loadings of 0.010 to 0 029 grains/scf.

1.5 TCA PRESSURE DROP DATA

During February and March 1975, a series of tests were made to obtain pressure drop data for a 3-bed, 4-grid TCA configuration. Pressure drop was determined as a function of gas velocity, liquid rate, sphere bed height, and type of spheres. It was found that flooding occurred at an overall pressure drop of 8 to 10 inches H_2O. Pressure drop was independent of type of sphere (5-gram HDPE versus TPR).

The data for non-flooding conditions were fitted to a correlaing equation. This equation replaces a correlation developed earlier for the for the TCA system with wire mesh grids. Bar-grids are presently used in place of the wire mesh grids.

Section 2

INTRODUCTION

In June 1968, a program was initiated under the direction of the Environmental Protection Agency (EPA)[*] to test a prototype lime and limestone wet-scrubbing system for removing sulfur dioxide and particulates from flue gases. The system was integrated into the flue gas ductwork of a coal-fired boiler at the Tennessee Valley Authority (TVA) Shawnee Power Station, Paducah, Kentucky. Bechtel Corporation of San Francisco was the major contractor and test director, and TVA was the constructor and facility operator.

The test facility consisted of three parallel scrubber systems: (1) a venturi followed by a spray tower, (2) a Turbulent Contact Absorber (TCA), and (3) a Marble-Bed Absorber. Each system was capable of treating approximately 10 Mw equivalent (30,000 acfm @ 300°F) of flue gas containing 1500 to 4500 ppm sulfur dioxide and 2 to 4 grains/scf of particulates.

The results of testing at the facility during the original program, which lasted from March 1972 to October 1974, are presented in Reference 1. The most significant reliability problem encountered during the testing program was associated with scaling and/or plugging of mist elimination surfaces. The TCA mist elimination system consisted of a wash tray in series with a chevron mist eliminator, both with underside washing. Long-term operability of this system was demonstrated at a scrubber gas velocity of 8.6 ft/sec.* The venturi/spray tower mist elimination system consisted of a chevron mist eliminator with underside washing Long-term operability of the venturi/spray tower system was not demonstrated. Operation of the Marble-Bed Absorber was discontinued in July 1973 (see Reference 1).

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[*] The National Air Pollution Control Administration prior to 1970.

In June 1974, the EPA, through its Office of Research and Development and Control Systems Laboratory, initiated a three-year Advanced Test Program at the Shawnee Facilty. Bechtel Corporation continued as the major contractor and test director, and TVA as the constructor and facility operator. The major goals established for the advanced program were: (1) to continue long-term testing with emphasis on demonstrating reliable operation of the mist elimination systems, (2) to investigate advanced process and equipment design variations for improving system reliability and process economics, and (3) to perform long-term (2 to 5 month) reliability testing on promising process and equipment design variations.

This report presents the results of advanced testing at the Shawnee facility from October 1974 through April 1975. During this period, the venturi/spray tower has been operated on lime while the TCA has been on limestone. Testing has been conducted, primarily, to evaluate the operability of modified venturi/spray tower and TCA mist elimination systems at increased gas velocities.

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*In this report, all gas velocities and liquid-to-gas ratios are at scrubber operating conditions, i.e., saturated gas at scrubber temperature. With flue gas operations, the scrubber temperature is approximately 125°F. The gas velocities are all superficial velocities.

Section 3

TEST FACILITY

Two parallel scrubbing systems are being operated during the advanced testing program. Scrubbers incorporated in these systems are:

(1) A venturi followed by a spray tower
(2) A Turbulent Contact Absorber (TCA)

Each system has its own slurry handling facilities and is capable of treating approximately 30,000 acfm of flue gas from the TVA Shawnee coal-fired boiler No. 10. This gas rate is equivalent to approximately 10 Mw of power plant generating capacity.

Boiler No. 10 normally burns a high-sulfur bituminous coal which produces SO_2 concentrations of 1500 to 4500 ppm and inlet particulate loadings of 2 to 4 grains/scf in the flue gas.

3.1 SCRUBBER SELECTION

The major criterion for scrubber selection was the potential for removing both sulfur dioxide and particulates at high efficiencies (sulfur dioxide removal greater than 80 percent and particulate removal greater than 99 percent). Other criteria considered in the selection of the scrubbers were:

- Ability to handle slurries without plugging or excessive scaling
- Reasonable cost and maintenance
- Ease of control
- Reasonable pressure drop

The venturi/spray tower and the TCA were chosen to meet these criteria. The venturi scrubber (manufactured by Chemical Construction Corp.) contains an adjustable throat that permits control of pressure drop under a wide range of flow conditions. The venturi is an effective particulate removal device, but it has limited capability for gas absorption in lime/limestone systems because of low slurry residence time. For this reason, the spray tower was included for additional absorption capability. The TCA scrubber (manufactured by Universal Oil Products and described in Reference 2) utilizes a fluidized bed of 1 1/2-inch-diameter, 5-gram hollow spheres which are free to move between retaining grids.

Figures 3-1 and 3-2 (drawn with major dimensions to scale) show the two scrubber systems along with the mist elimination systems selected for de-entraining slurry in the exit gas streams. The chevron mist eliminators used during the testing on the two scrubber systems are depicted, to scale, in Figure 3-3. The cross-sectional area of the TCA scrubber is 32 ft^2 in the scrubbing section and 49 ft^2 in the mist elimination section. The cross-sectional area of the spray tower is 50 ft^2 in both the scrubbing section and the mist elimination section. Future planned modifications to the scrubber and mist elimination systems are discussed in Section 4.

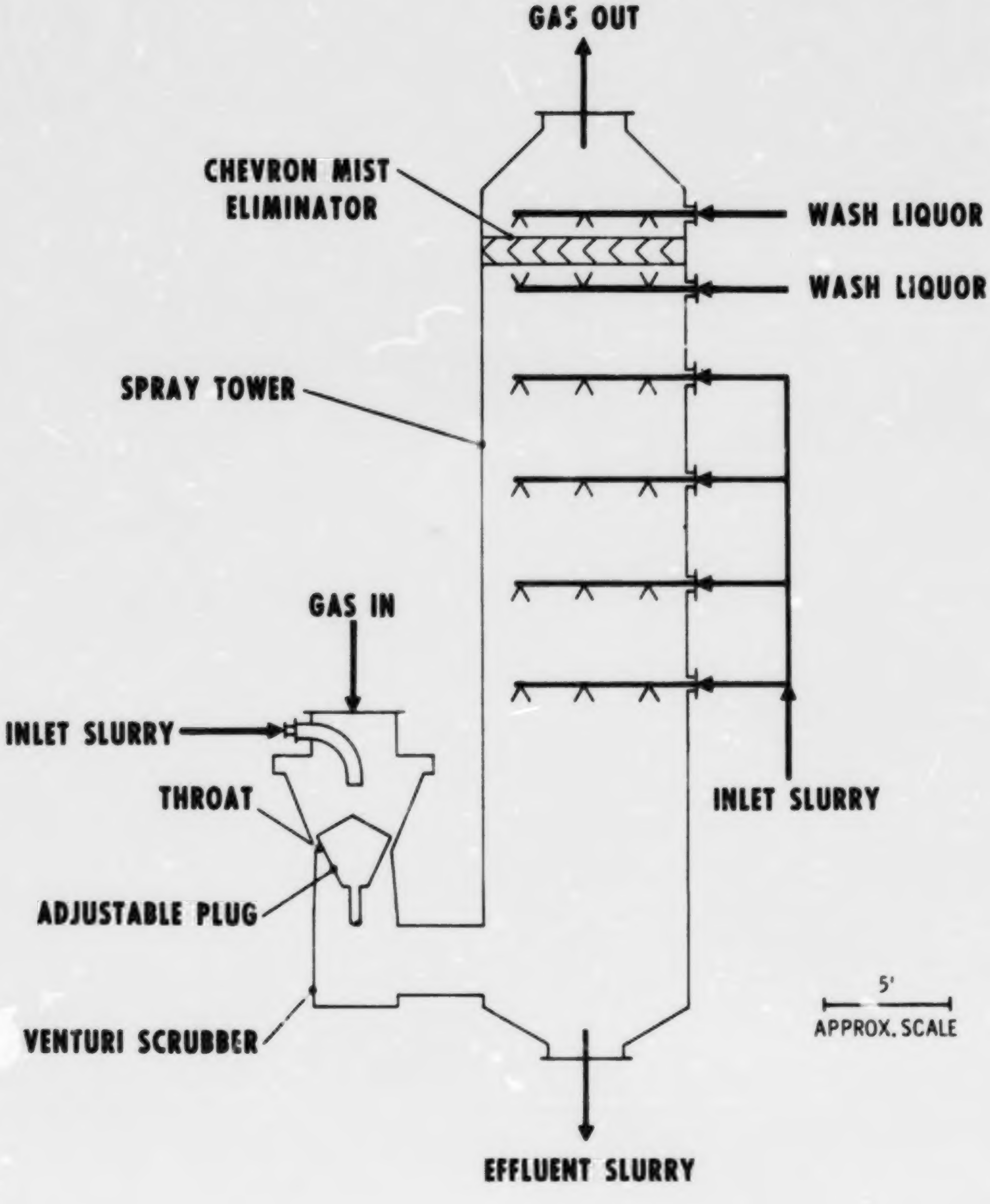

GAS OUT
CHEVRON MIST ELIMINATOR
WASH LIQUOR
WASH LIQUOR
SPRAY TOWER
GAS IN
INLET SLURRY
THROAT
ADJUSTABLE PLUG
VENTURI SCRUBBER
INLET SLURRY
5'
APPROX. SCALE
EFFLUENT SLURRY

Figure 3-1. Schematic of Venturi Scrubber and Spray Tower

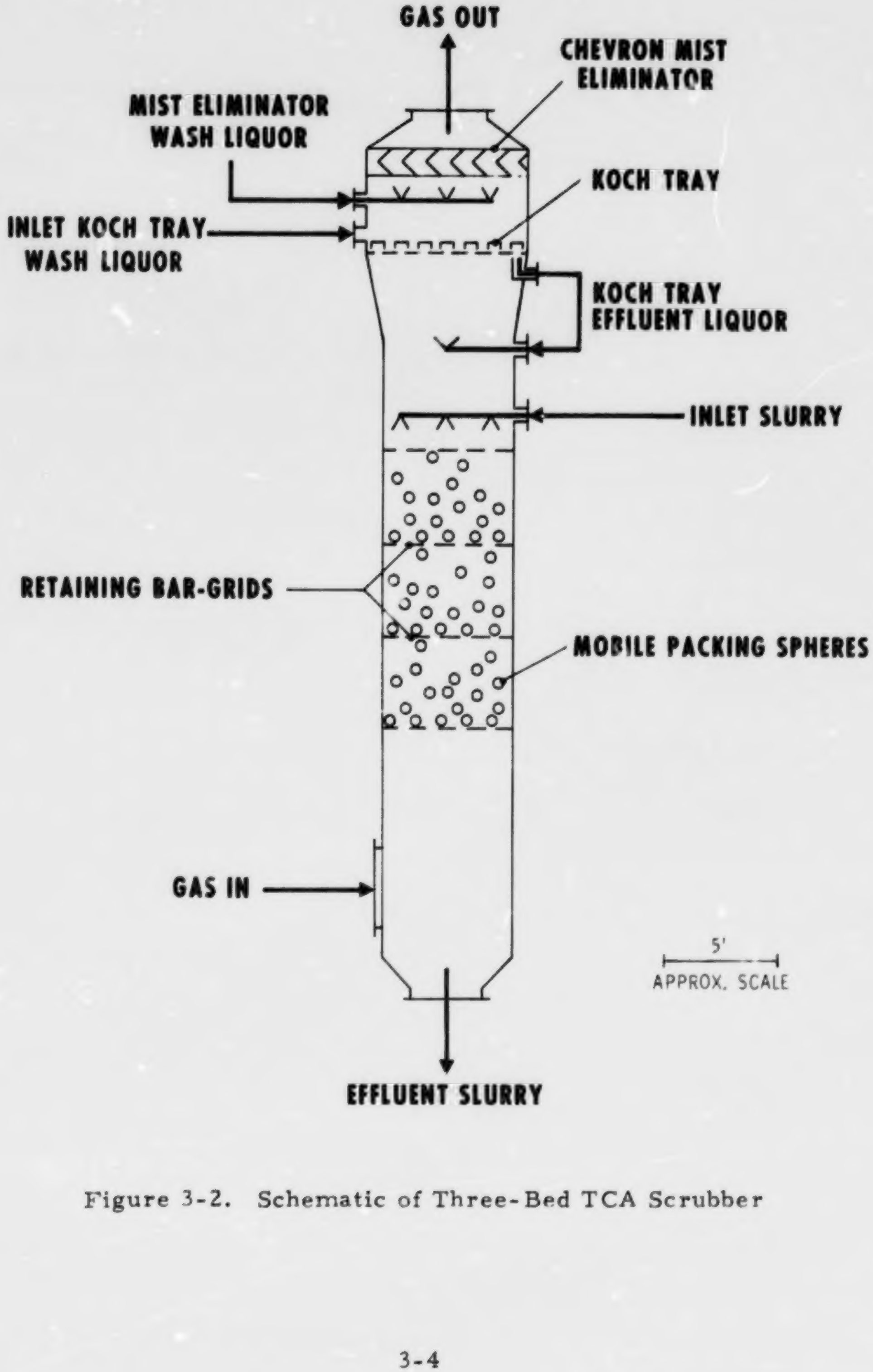
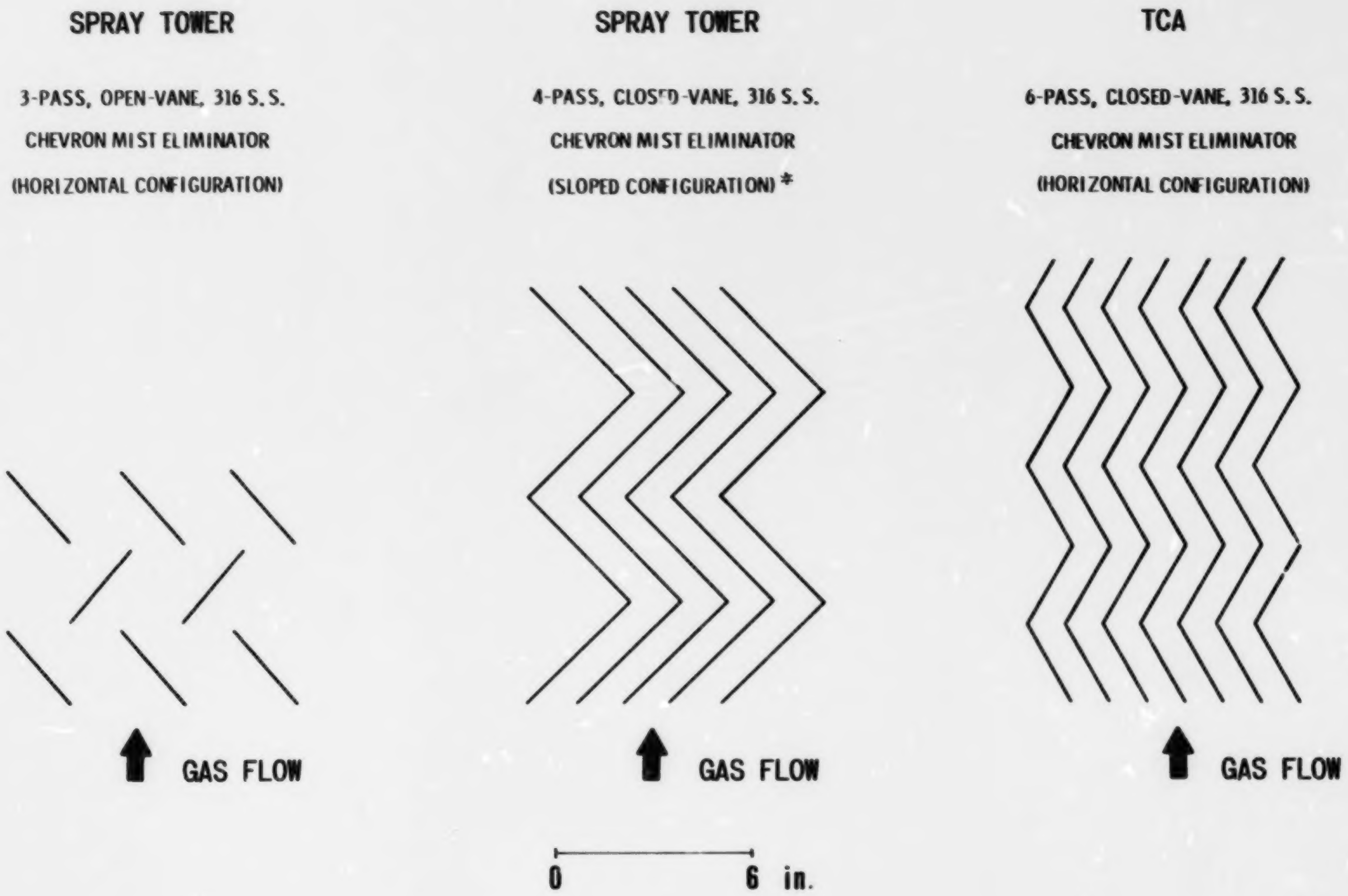

GAS OUT
CHEVRON MIST ELIMINATOR
MIST ELIMINATOR WASH LIQUOR
KOCH TRAY
INLET KOCH TRAY WASH LIQUOR
KOCH TRAY EFFLUENT LIQUOR
INLET SLURRY
RETAINING BAR-GRIDS
MOBILE PACKING SPHERES
GAS IN
5'
APPROX. SCALE
EFFLUENT SLURRY

Figure 3-2. Schematic of Three-Bed TCA Scrubber


SPRAY TOWER
3-PASS, OPEN-VANE, 316 S. S.
CHEVRON MIST ELIMINATOR
(HORIZONTAL CONFIGURATION)
GAS FLOW
SPRAY TOWER
4-PASS, CLOSED-VANE, 316 S. S.
CHEVRON MIST ELIMINATOR
(SLOPED CONFIGURATION) *
GAS FLOW
TCA
6-PASS, CLOSED-VANE, 316 S. S.
CHEVRON MIST ELIMINATOR
(HORIZONTAL CONFIGURATION)
GAS FLOW
0
6 in.

*Sections installed in a 16 sided pyramid with a 30° slope. Total face area was 58 ft^2.

Figure 3-3. Test Facility Mist Eliminator Configurations

3.2 SYSTEM DESCRIPTION

The Shawnee test facility contains five major areas:

(1) The scrubber area (including tanks and pumps)

(2) The operations building area (including laboratory area, electrical gear, centrifuge, and filter)

(3) The thickener area (including pumps and tanks)

(4) The utility area (including air compressors, air dryer, limestone storage silos, mix tanks, gravimetric feeder, and pumps)

(5) The pond area

The test facility has been so designed that a varied number of different scrubber internals and piping configurations can be used with each scrubber system. For example, the TCA scrubber can be operated with one, two, or three beds of spheres or with only the support grids. Solid separation can be achieved with a clarifier alone or with a clarifier in combination with a filter or a centrifuge.

Typical system configurations for lime testing with the venturi/spray tower and limestone testing with TCA scrubber are shown schematically in Figures 3-4 and 3-5, respectively. Such process details as flue gas saturation (humidification) sprays are not shown.

For both systems, gas is withdrawn from the boiler ahead of the power plant particulate removal equipment so that all the entrained particulate matter (fly ash) can be introduced into the scrubber. The gas flow rate to each scrubber is measured by venturi flow meters and controlled by

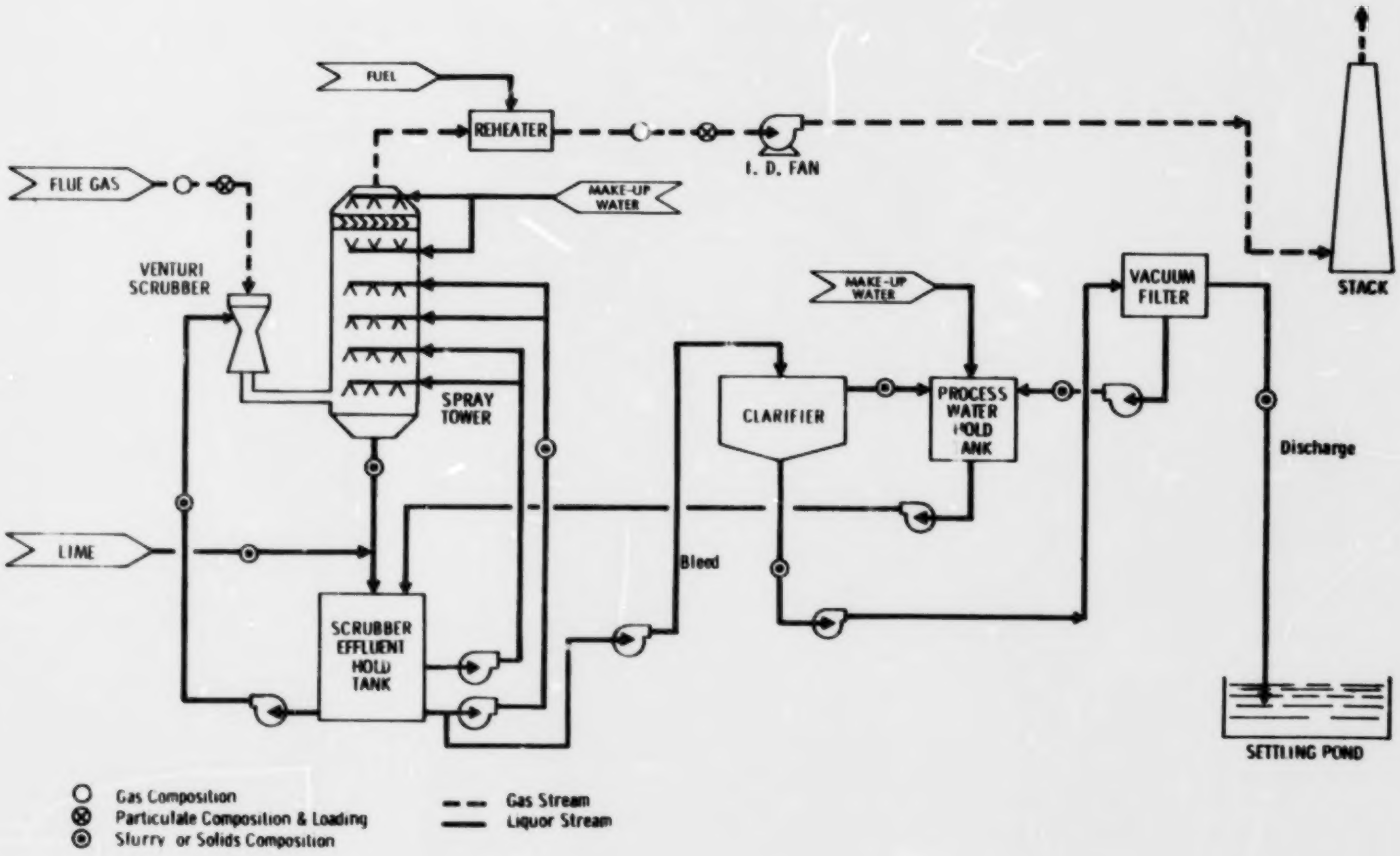

FUEL
REHEATER
I. D. FAN
STACK
FLUE GAS
MAKE-UP WATER
VENTURI SCRUBBER
SPRAY TOWER
MAKE-UP WATER
VACUUM FILTER
CLARIFIER
PROCESS WATER HOLD TANK
Discharge
LIME
Bleed
SCRUBBER EFFLUENT HOLD TANK
SETTLING POND
○ Gas Composition
⊗ Particulate Composition & Loading
⊙ Slurry or Solids Composition
– – Gas Stream
— Liquor Stream

Figure 3-4. Typical Process Flow Diagram For Venturi/Spray Tower System

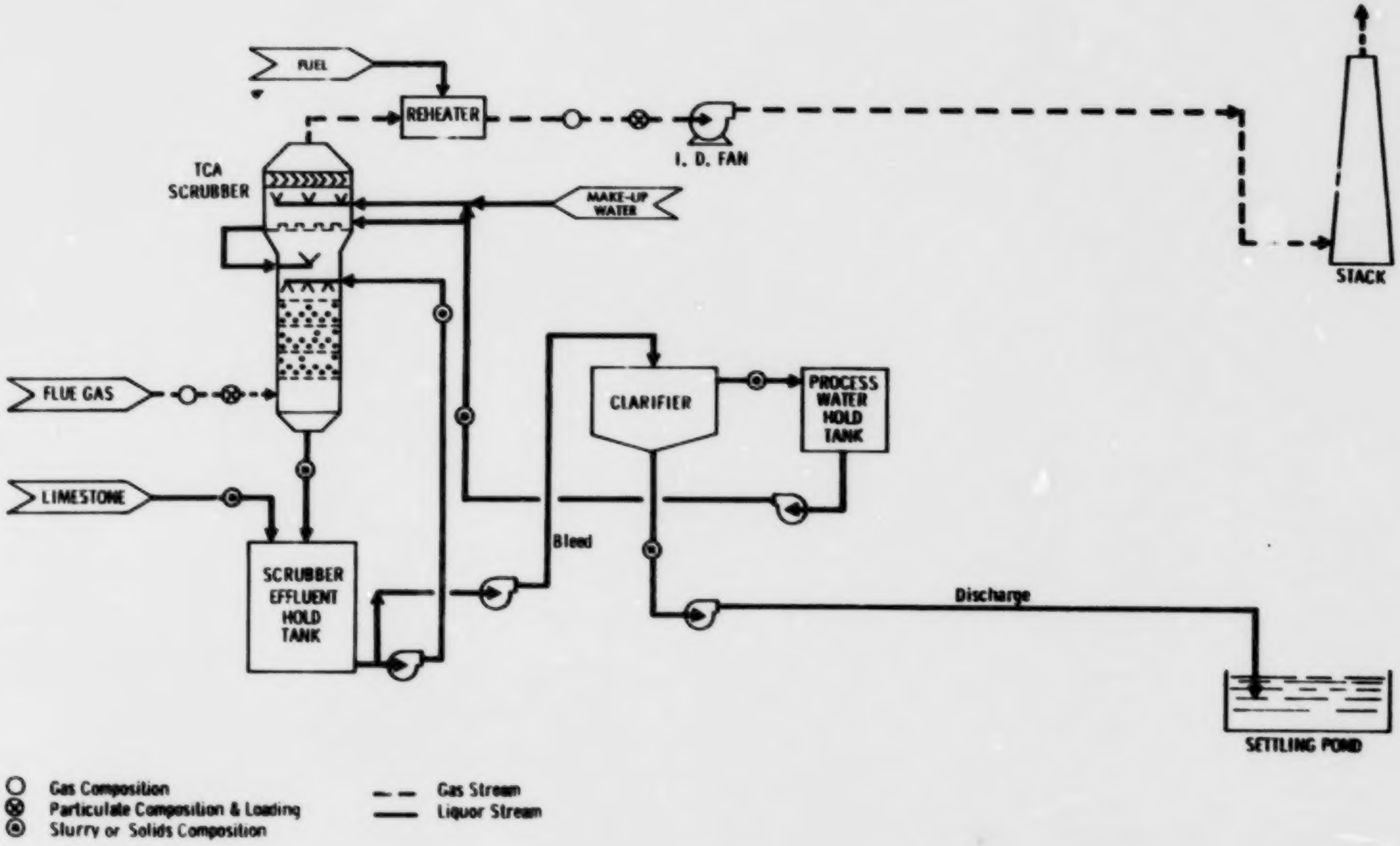

FUEL
REHEATER
I. D. FAN
STACK
TCA SCRUBBER
MAKE-UP WATER
FLUE GAS
LIMESTONE
CLARIFIER
PROCESS WATER HOLD TANK
SCRUBBER EFFLUENT HOLD TANK
Bleed
Discharge
SETTLING POND
○ Gas Composition
⊗ Particulate Composition & Loading
⊙ Slurry or Solids Composition
– – Gas Stream
—— Liquor Stream

Figure 3-5. Typical Process Flow Diagram For TCA System

dampers on the induced-draft fans. The concentration of sulfur dioxide in the inlet and outlet gas streams is determined continuously by Du Pont photometric analyzers.

The scrubbing systems are controlled from a central graphic panelboard. An electronic data acquisition system is used to record the operating data. The system is hard wired for data output in engineering units directly on magnetic tape. On-site display of selected information is available. Important process control variables are continuously recorded. Trend recorders are provided for periodic monitoring of selected data sources.

3.3 EPA PILOT PLANT SUPPORT

Two smaller scrubbing systems (300 acfm each), which are capable of operating over a wide range of conditions, have been installed at the EPA facility in Research Triangle Park, North Carolina. The small pilot scale scrubber systems are capable of simulating the Shawnee scrubber systems with excellent agreement in the lime/limestone wet-scrubbing chemistry. Preliminary data is generated on the pilot scale system to verify and guide the selection of those promising concepts which should logically be investigated on the larger scale Shawnee units. Some of the results from the support program have been presented in References 3 and 4.

Section 4

TEST PROGRAM

This section contains a description of the Shawnee Advanced Test Program, which is tentatively scheduled to run from June 1974 through June 1977.

4.1 TEST PROGRAM OBJECTIVES AND SCHEDULE

The goals of the test program are:

(1) To continue long-term testing with emphasis on demonstrating reliable operation of the mist elimination systems.

(2) To investigate advanced process and equipment design variations for improving system reliability. For example, testing will be conducted with magnesium ion (MgO) addition in order to operate the scrubber systems with liquors unsaturated with respect to calcium sulfate (see Reference 3).

(3) To investigate advanced process and equipment design variation for improving system economics. For example, testing will be conducted to investigate the practical upper limit of the gas velocity (i.e., minimum scrubber size) at which the scrubber mist elimination systems can be reliably operated. Also, tests will be conducted to evaluate system performance under conditions of minimum energy consumption for the desired levels of SO_2 and particulate removal.

(4) To evaluate process variations for substantially increasing limestone utilization and reducing sludge production. Tests will be conducted with scrubber effluent passing through three

stirred tanks in series to approach a "plug-flow" condition and at reduced scrubber liquor pH to increase limestone utilization (see Reference 4).

(5) To perform long-term (2 to 5 month) reliability testing on advanced process and equipment design variations.

(6) To evaluate scrubber operability during variable load (e.g., cycling gas rate) operation.

(7) To investigate methods of improving waste solids separation. This may include testing of a multiple-plate thickener, use of coagulants, attempts to relate sludge characteristics to operating conditions, and operational improvements of the centrifuge and filter.

(8) To determine the effectiveness of existing technology for producing an improved throwaway sludge product. Tests will be conducted to evaluate schemes for oxidizing sludge to calcium sulfate (gypsum)/fly ash mixtures, in order to improve solids settling characteristics and to reduce the chemical oxygen demand (COD) of the sludge.

(9) To evaluate the effectiveness of three commercially offered sludge fixation processes and of untreated sludge disposal. Fixed sludges (Chemfix, Dravo, and IUCS) and untreated lime and limestone sludges are being continuously monitored in ponds at the Shawnee site. Aerospace Corporation is the major contractor and test director for this effort.

(10) To evaluate system performance and reliability without fly ash in the flue gas. Tests will be conducted with flue gas taken downstream of the Shawnee Boiler No. 10 electrostatic precipitator, i.e., with less than 0.1 grain/scf of particulate in the inlet flue gas.

(11) To determine the practical upper limits of SO_2 removal efficiency. Tests will be conducted to determine the practical upper limit of SO_2 removal by increasing the scrubber slurry pH, increasing the slurry rate, increasing the scrubber gas pressure drop, and adding magnesium ion (MgO) to the slurry.

(12) To evaluate the TCA performance with lime and the venturi/spray tower performance with limestone.

(13) To characterize stack gas emissions including outlet particulate mass loading and size distribution, slurry entrainment, and total sulfate emissions.

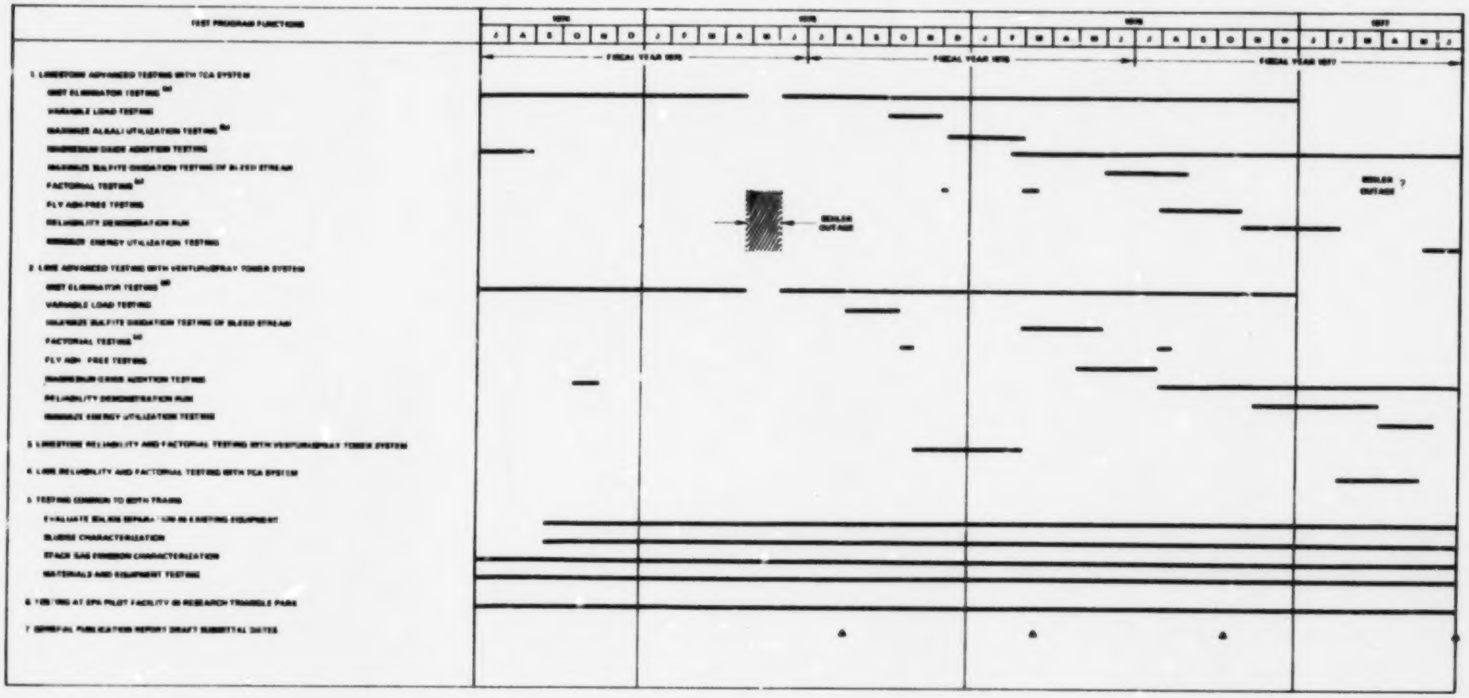
(14) To evaluate, under the direction of TVA, corrosion and wear of alternative plant equipment components and materials.

(15) To develop a computer program, in conjunction with TVA, for the design and cost comparison of full-scale lime and limestone systems.

The test program schedule, based on the defined objectives, is presented in Figure 4-1. As can be seen in the figure, as of the May 1975 boiler outage, tests were in progress to demonstrate reliability of mist elimination systems at increased gas velocity, i.e., at 8.0 ft/sec in the spray tower and 12 ft/sec in the TCA.

4.2 CLOSED LIQUOR LOOP OPERATION

A closed liquor loop is achieved when the raw water input to the system is equal to the water normally exiting the system in the settled sluge and in the humidified flue gas. For lime/limestone wet-scrubbing systems, the solids concentration in the settled sludge is normally equal to or greater than 38 percent by weight. If waste solids are purged at a concentration below 38 percent or if a separate liquor purge is taken, then the system is considered to be in open liquor loop operation.



NOTE: DASHED LINES REPRESENT SEQUENCES WHICH MAY BE CONTINUED DURING THE PERIOD INDICATED

(a) INCLUDES TESTING AT 12.5 ft/sec GAS VELOCITY

(b) INCLUDES TESTING WITH SERIES HOLD TANKS AND AT REDUCED SCRUBBER SLURRY pH

(c) INCLUDES "MAXIMIZING SO_2 REMOVAL EFFICIENCY" TESTING

(d) INCLUDES TESTING AT MAXIMUM ATTAINABLE SPRAY TOWER GAS VELOCITY (~ 9.5 ft/sec)

Figure 4-1. Shawnee Advanced Test Schedule

With few exceptions, the advanced program tests are being conducted in closed liquor loop operation. The exceptions are typically short exploritory runs with limited objectives. They will be noted as open liquor loop tests when they occur.

4.3 ANALYTICAL PROGRAM

Samples of slurry, flue gas, limestone, lime, and coal are taken periodically for chemical analyses, particulate mass loading, and limestone reactivity tests during the testing. Locations of slurry and gas sample points are shown on Figures 3-4 and 3-5. A summary of the analytical methods for determining important species in the slurry solids and slurry liquor is presented in Table 4-1. A laboratory procedures manual is being developed for distribution on request by the end of the year. A listing of the compositions of the raw materials used in the testing program is presented in Appendix C.

Four Du Pont photometric analyzers are used for continuous SO_2 gas analyzing at the inlets and outlets of both scrubbers. Values of pH are monitored with Universal Interlox pH analyzers. Scrubber inlet and outlet liquor pH and Koch Tray outlet liquor pH are monitored continuously. Process water hold tank pH is monitored periodically. Two Universal Interlox electrolytic analyzers are used to monitor electrical conductivity. A modified EPA particulate train (manufactured by Aerotherm/Acurex Corporation) is used to measure mass loading at the scrubber inlets and outlets.

Table 4-1

FIELD METHODS FOR BATCH CHEMICAL ANALYSIS OF SLURRY AND ALKALI SAMPLES

SPECIES DESIRED	FIELD METHOD	
	SOLIDS	LIQUIDS
Sodium	-	Atomic Absorption
Potassium	-	Atomic Absorption
Calcium	X-ray Fluorescence	Atomic Absorption
Magnesium	X-ray Fluorescence	Atomic Absorption
Sulfite	Amperometric Titration	Amperometric Titration
Total Sulfur	X-ray Fluorescence	$Ba(ClO_4)2$ Titration
Carbonate	Evolution	Infrared Analyzer
Chlorides	-	Potentiometric Titration

4.4 DATA ACQUISITION AND PROCESSING

Operating and analytical data are recorded automatically onto magnetic tapes at the test facility. Additional data are recorded manually in operating logs and graphs by on-site personnel. All data are sent to the Bechtel Corporation offices in San Francisco for processing. In San Francisco, data received from the test facility are entered into a data base. The data is sorted, further calculations made (e.g., percent sulfite oxidation, stoichiometric ratio), and reports are prepared which present the data covering a specified period for a given scrubber. After startup problems, the data gathering system has functioned well in providing an up-to-date log of the scrubber operations.

4.4.1 Operating Data (Scan Data Acquisition)

Over 150 pieces of scan data (flow rate, temperature, pH, etc.) are recorded automatically at fixed time intervals onto magnetic tape at the test facility. The scan data acquisition system was designed and installed by Electronic Modules Corporation, and the tape recorder was supplied by Cipher Data Products Corporation. A backup printed record on paper tape is available if the recorder malfunctions.

4.4.2 Analytical Data

The analytical data acquisition system, which records the results of laboratory analyses on magnetic tape, was designed and (in part) installed by Radian Corporation. A mini-computer receives inputs, either directly from laboratory instrumentation or indirectly by reading cards. The mini-computer performs certain calculations and enters the resultant data on magnetic tape. The system generates, on-site, a printed summary sheet of analytical data for each sample.

Section 5

VENTURI/SPRAY TOWER LIME RELIABILITY TEST RESULTS

Performance and analytical data from lime reliability testing on the venturi/spray tower system from October 1974 through April 1975 are presented in this section, along with an evaluation of each test and the conclusions drawn, to date. Results of lime reliability tests prior to October 1974 have been reported in Reference 1.

5.1 PERFORMANCE DATA AND TEST EVALUATION

A summary of the test conditions and results of lime reliability tests on the venturi/spray tower is presented in Table 5-1.* Properties of raw materials such as lime and coal used during the tests can be found in Appendix C. Selected operating data for tests which lasted more than one week are graphically presented in Appendix D. Average scrubber and clarifier overflow liquor compositions and the corresponding calculated percent sulfate (gypsum) saturations are given in Appendix E.** An evaluation and discussion of each test is presented in the following sections.

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*Lime reliability runs made prior to October 1974 have been included in this table.

**The degree of liquor saturation with $CaSO_4 \cdot 2H_2O$ at 50°C was calculated with the use of the Bechtel modified Radian program. See Reference 1 for a listing of this program.

Table 5-1

SUMMARY OF LIME RELIABILITY TESTS ON VENTURI/SPRAY TOWER SYSTEM

Run No.	601-1A			602-1A	603-1A
Start-of-Run Date	10/9/73			3/19/74	4/2/74
End-of-Run Date	1/8/74			4/1/74	4/19/74
On Stream Hours	2193			393	395
Gas Rate, acfm @ 330°F	25,000			25,000	25,000
Spray Tower Gas Vel, fps @ 125°F	6.7			6.7	6.7
Venturi/Spray Tower Liquor Rates, gpm	600/1200			600/1200	600/1200
Spray Tower L/G, gal/mcf	60			60	60
Percent Solids Recirculated	7-9			7.5-9.5	13.5-16
Effluent Residence Time, min.	12			12	12
Solids Disposal System	Clarifier Only (10/9-11/7)	Clarif & Intermittent Filter (11/7-12/15)	Clarifier & Filter (12/15-1/8)	Clarifier & Filter	Clarifier & Filter
Stoichiometric Ratio, moles Ca added/mole SO_2 absorbed	1.01-1.2	1.02-1.18	1.04-1.19	1.02-1.18	1.00-1.13
Avg % Lime Utilization, 100x moles SO_2 abs./mole Ca added	87	91	90	91	94
Inlet SO_2 Concentration, ppm	1600-3900	2100-4000	2100-4600	2100-3800	2100-4300
Percent SO_2 Removal	68-91	75-95	75-95	87-97	85-98
Scrubber Inlet pH Range	7.4-8.5	7.5-8.5	7.7-8.4	7.6-8.3	7.8-8.2
Scrubber Outlet pH Range	4.7-5.5	4.7-5.5	4.8-5.3	4.9-5.4	4.8-5.3
Percent Sulfur Oxidized	10-30	10-30	10-30	5-28	12-22
Loop Closure, % Solids Dischg.	20-26	20-27	42-52	42-48	46-54
Calculated % Sulfate Saturation in Scrubber Inlet Liquor @ 50°C	150	120	180	165	135
Dissolved Solids, ppm	5700-7500	4600-7300	9800-12,300	9500	8200-10,900
Total ΔP Range, Excluding Mist Eliminator in. H_2O	11.0-11.5	11.0-12.0	11.7-12.3	11.0-12.0	11.0-12.0
Venturi ΔP, in. H_2O	9	9	9	9	9
Mist Eliminator ΔP, in. H_2O	0.16-0.31	0.21-0.51	0.51-1.26	0.19-0.27	0.16-0.33
Absorbent	Lime slurried to 20 wt% with makeup water and added to EHT.			Lime slurried to 20 wt% with makeup water and added to EHT.	Lime slurried to 20 wt% with makeup water and added to EHT.
Mist Eliminator	10/9 - 12/15: Bottom washed with available makeup water (~14 gpm) plus available clarified liquor (~26 gpm). Continuous wash rate of 0.8 gpm/ft^2. 12/15 - 1/8: Bottom washed with available makeup water (~5 gpm) plus available clarifier liquor (~45 gpm). Wash rate of 1 gpm/ft^2 on cycle of 3-1/2 min on/1-1/2 min off. Also, top was washed once/wk with fresh water for 5 min during last 4 wks.			Bottom washed with available makeup water (~5 gpm) plus available clarified liquor (~34 gpm). Wash rate of 1 gpm/ft^2 on cycle of ~ 4 min on/1min off.	Bottom washed with available makeup water (~5 gpm) plus available clarified liquor (~21 gpm). Wash rate of 1 gpm/ft^2 on cycle of ~ 1-1/2 min on/1-1/2 min off.
Scrubber Internals	All nozzles (7/header) on top 3 headers sprayed downward. Bottom header nozzles (7) sprayed upward.			All nozzles on 4 headers sprayed downward. 7 nozzles/header on top 3 headers. 6 nozzles on bottom header.	All nozzles on 4 headers sprayed downward. 7 nozzles/header on top 3 headers. 6 nozzles on bottom header.
System Changes Before Start of Run	System (scrubber and mist eliminator) cleaned.			System cleaned chemically (Na_2CO_3/sugar/limestone/flyash soln.) followed by mech. cleaning. EHT sealed. Installed external combustion reheater. Changed nozzles on bottom spray header to spray downward instead of upward. Capped middle nozzles on bottom header.	Mist eliminator cleaned.
Method of Control	Scrubber inlet pH controlled at 8.0 ± 0.2			Scrubber inlet pH controlled at 8.0 ± 0.2	Scrubber inlet pH controlled at 8.0 ± 0.2
Run Philosophy	Initially started as lime reliability verification test. Subsequently, due to apparent reliability of the run, decision was made that test continue as long-term reliability test.			Intended long-term. Sealed EHT in attempt to reduce sulfite oxidation and thereby degree of sulfate saturation.	Intended long-term. Recirculated 15% solids in attempt to reduce degree of sulfate saturation. EHT sealed.
Results	Routine inspection on 11/7/74 showed system was generally clean after 666 hours of operation with clarifier only for solids disposal. Run was terminated on 1/8/74 due to ID fan vibration and rapidly increasing pressure drop across mist. elim. Sulfate based scale formed on most scrubber walls and in slurry piping. Top of mist eliminator 80% plugged with solids that fell from outlet duct-work. Mist eliminator top vanes heavily scaled (300 mils avg.).			Run terminated due to scale (125 mils avg) and solids deposits on mist eliminator top vanes. Sulfite oxidation and sulfate saturation were not reduced. Steady state operation not achieved.	Degree of sulfate saturation was reduced, but run was terminated due to scale (60 mils avg.) and solids buildup on the mist eliminator top vanes.

Table 5-1 (continued)

SUMMARY OF LIME RELIABILITY TESTS ON VENTURI/SPRAY TOWER SYSTEM

Run No.	604-1A	605-1A	606-1A	608-1A
Start-of-Run Date	4/26/74	7/31/74	8/7/74	9/21/74
End-of-Run Date	7/18/74	8/6/74	8/14/74	9/17/74
On Stream Hours	1828	141	170	610
Gas Rate, acfm @ 330°F	25,000	25,000	25,000	25,000
Spray Tower Gas Vel. fps @ 125	7	6.7	6.7	6.7
Venturi/Spray Tower Liquor Rates, gpm	min. (~100)/1200	min. (~100)/1200	min. (~100)/1200	600/1200
Spray Tower L/G, gal/mcf	60	60	60	60
Percent Solids Recirculated	7.5-9.0	8.0-9.3	7.7-9.0	7.7-9.4
Effluent Residence Time, min.	17	17	17	12
Solids Disposal System	Clarifier & Filter	Clarifier & Filter	Clarifier	Clarifier & Filter
Stoichiometric Ratio, moles Ca added/mole SO_2 absorbed	1.03-1.30	1.10-1.17	1.10-1.15	1.05-1.25
Avg % Lime Utilization, 100x moles SO_2 abs./mole Ca added	88	.8	89	87
Inlet SO_2 Concentration, ppm	2000-3800	2500-3300	2400-3200	2000-3750
Percent SO_2 Removal	70-92	73-81	67-79	75-95
Scrubber Inlet pH Range	7.7-8.4	8.8-9.2	7.8-8.2	7.6-8.4
Scrubber Outlet pH Range	4.5-5.4	4.9-5.1	5.0-5.2	4.8-5.1
Percent Sulfur Oxidized	8-30	12-26	12-22	12-28
Loop Closure, % Solids Dischg.	50-60	48-52	18-23	48-58
Calculated % Sulfate Saturation in Scrubber Inlet Liquor @ 50°C	130	115	120	130
Dissolved Solids, ppm	11,600-13,700	6,000-7,400	5,000-7,000	7,500-9,500
Total ΔP Range, Excluding Mist Eliminator, in. H_2O	3.3-3.8	3.2-3.9	3.6-3.7	11.5-12.0
Venturi ΔP, in. H_2O	1.2-1.5 (Plug 100% open)	1.5-2.0 (Plug 100% open)	1.9-2.3 (Plug 100% open)	9
Mist Eliminator ΔP, in. H_2O	0.20-1.25	0.23-0.28	0.23-0.31	0.22-0.44
Absorbent	Lime slurried to 20 wt % with makeup water and added to scrubber downcomer.	Lime slurried to 20 wt% with makeup water and added to scrubber downcomer.	Lime slurried to 20 wt% with makeup water and added to scrubber downcomer.	Lime slurried to 20 wt% with makeup water and added to scrubber downcomer.
Mist Eliminator	Bottom washed with available makeup water (~5 gpm) plus available clarified liquor (~35 gpm). Wash rate of 1 gpm/ft² on cycle of ~3 1/2 min on/1 1/2 min off.	Bottom washed with available makeup water only (~5 gpm). Wash rate of 0.4 gpm/ft² on cycle of ~1 min on/4 min. off.	Bottom washed continuously with 15 gpm (0.3 gpm/ft²) raw water only. (Rate was greater than available makeup water).	Bottom washed with available makeup water only (~5.5 gpm). Wash rate of 150 gpm (3 gpm/ft²) for approx. 9 min. every 4 hours.
Scrubber Internals	All nozzles on 4 headers sprayed downward. 7 nozzles/header on top 3 headers, 6 nozzles on bottom header.	All nozzles on 4 headers sprayed downward. 7 nozzles/header on top 3 headers, 6 nozzles on bottom header.	All nozzles on 4 headers sprayed downward. 7 nozzles/header on top 3 headers, 6 nozzles on bottom header.	All nozzles on 4 headers sprayed downward. 7 nozzles/header on top 3 headers, 6 nozzles on bottom header.
System Changes Before Start of Run	Mist eliminator and outlet duct cleaned. Sealed EHT provided with N_2 gas purge. EHT overflow blanked. Lime slurry makeup added to scrubber downcomer.	System cleaned.	Mist eliminator cleaned.	Mist eliminator cleaned. Provided for Freon gas blanket over EHT.
Method of Control	Scrubber inlet pH controlled at 8.0 ± 0.2	Scrubber inlet pH controlled at 9.0 ± 0.2	Scrubber inlet pH controlled at 8.0 ± 0.2	Scrubber inlet pH controlled at 8.0 ± 0.2
Run Philosophy	Intended 2 wks. To observe sulfite oxidation and degree of sulfate saturation with lime add'n to downcomer, minimum slurry rate to venturi, sealed EHT purged with N_2 gas, and 8% solids recirculated.	Intended long-term. Control at higher pH in attempt to reduce sulfite oxidation and thereby degree of sulfate saturation. Wash mist eliminator with water only.	Intended short-term. Mist eliminator washed continuously with raw water only (at rate greater than available makeup water).	Int'd 2 wks. 12 min res time, venturi in service. EHT sealed with Freon. Mist elim. on 4 hr wash cycle. Observe effects of lime add'n to downcomer and sealed EHT (compare with Run 601-1A).
Results	Degree of sulfate saturation was about 130%. Solids from outlet duct fell to top of mist eliminator. Run was terminated due to heavy scale (500 mils avg.) and solids buildup on mist eliminator.	Run was terminated due to scale formation (up to 150 mils) on top mist eliminator vanes.	Run was terminated due to scale formation (50 mils avg.) on top mist eliminator vanes.	Run terminated due to slight increase in mist eliminator ΔP. Inspection revealed scale buildup (88 mils avg.) on the mist eliminator top vanes.

Table 5-1 (continued)

SUMMARY OF LIME RELIABILITY TESTS ON VENTURI/SPRAY TOWER SYSTEM

Reproduced from best available copy.

Run No.	609-1A	610-1A	611-1A	618-1A
Start-of-Run Date	9/20/74	10/2/74	10/24/74	11/21/74
End-of-Run Date	10/2/74	10/13/74	11/11/74	12/2/74
On Stream Hours	277	251	192	235
Gas Rate, acfm @ 330°F	25,000	25,000	25,000	25,000
Spray Tower Gas Vel, fps @ 125°F	6.7	6.7	6.7	6.7
Venturi/Spray Tower Liquor Rates, gpm	600/1200	600/1200	600/1200	min (~100)/1200
Spray Tower L/G, gal/mcf	60	60	60	60
Percent Solids Recirculated	7.9-9.0	7.8-8.6	8.0-9.3	7.5-9.6
Effluent Residence Time, min.	24	24	6	17
Solids Disposal System	Clarifier & Filter	Clarifier & Filter	Clarifier & Filter	Clarifier
Stoichiometric Ratio, moles Ca added/mole SO_2 absorbed	1.07-1.25	1.10-1.25	0.93-1.05[a]	1.15-1.22
Avg. % Lime Utilization, 100x moles SO_2 abs./mole Ca added	87	85	101[a]	84
Inlet SO_2 Concentration, ppm	2250-3600	1800-3800	2250-3750	2600-4250
Percent SO_2 Removal	80-96	87-98	96-99	57-77
Scrubber Inlet pH Range	7.6-8.6	7.8-8.4	6.9-7.2	7.0-8.1
Scrubber Outlet pH Range	4.7-5.4	4.8-6.0	5.4-6.3	4.8-5.1
Percent Sulfur Oxidized	12-30	16-26	15-24	10-28
Loop Closure, % Solids Dischg.	47-52	43-48	44-49	16-21
Calculated % Sulfate Saturation in Scrubber Inlet Liquor @ 50°C	110	145	45	140
Dissolved Solids, ppm	8,000-10,000	9,000-12,000	17,000-21,000	4,100-6,100
Total ΔP Range, Excluding Mist Eliminator, in. H_2O	11.0-11.9	11.0-12.2	10.4-12.0	3.15-4.25
Venturi ΔP, in. H_2O	9	9	9	1.8-1.9 (Plug 100% open)
Mist Eliminator ΔP, in. H_2O	0.25-0.28	0.25-0.31	0.55-0.60	0.40-0.60
Absorbent	Lime slurried to 20 wt% with makeup water and added to scrubber downcomer.	Lime slurried to 20 wt% with makeup water and added to effluent hold tank.	Lime slurried to 20 wt% with makeup water and added to scrubber downcomer.	Lime slurried to 20 wt% with makeup water and added to scrubber downcomer.
Mist Eliminator	Bottom washed with makeup at 2.7 gpm/ft² for ~8 min every 4 hrs. Simultaneous top wash with remaining makeup at 1 gpm/ft² through a single nozzle covering about 14 ft². Total makeup ~5 gpm avg.	Bottom washed with makeup at 2.7 gpm/ft² for ~8 min every 4 hrs. Simultaneous top wash with remaining makeup at 1 gpm/ft² through a single nozzle covering about 14 ft². Total makeup ~5 gpm avg.	Bottom washed continuously at 0.69 gpm/ft² using a mixture of ~5 gpm fresh water and ~35 gpm clarified liquor.	Bottom washed continuously at 0.26 gpm/ft² using 15 gpm raw water (three times required makeup water rate).
Scrubber Internals	All nozzles on 4 headers sprayed downward. 7 nozzles/header on top 3 headers. 6 nozzles on bottom header.	All nozzles on 4 headers sprayed downward. 7 nozzles/header on top 3 headers. 6 nozzles on bottom header.	All nozzles on 4 headers sprayed downward. 7 nozzles/header on top 3 headers. 5 nozzles on bottom header.	All nozzles on 4 headers sprayed downward. 7 nozzles/header on top 3 headers. 5 nozzles on bottom header.
System Changes Before Start of Run	Mist eliminator and outlet duct cleaned. A single nozzle installed to provide top wash for one section of mist eliminator and several holes drilled in the top vanes of a second section.	Relocated lime addition to effluent hold tank.	System cleaned. Installed sloped mist eliminator and MgO feeder. Relocated lime addition to scrubber downcomer. Effluent hold tank agitator lowered.	System cleaned
Method of Control	Scrubber inlet pH controlled at 8.0 ± 0.2.	Scrubber inlet pH controlled at 8.0 ± 0.2.	Scrubber inlet pH controlled at 7.0 ± 0.2.	Scrubber inlet pH controlled at 8.0 ± 0.2.
Run Philosophy	Intended 2 wks. To observe the effect of mist eliminator top wash (on one section) and the effect of increased residence time on sulfate saturation.	Intended 2 wks. To observe the effect on sulfate saturation of lime addition to the effluent hold tank vs addition to the downcomer.	To verify the ability to run unsaturated with respect to calcium sulfate with MgO add'n at 6 min. effluent residence time.	Intended 1 wk. To observe rate of scale buildup on sloped mist eliminator using a continuous fresh water bottom wash.
Results	Run terminated as planned. Sulfate saturation reduced to 110%. Mist eliminator top vanes clean where top washed.	Run terminated as planned. Sulfate saturation 145%. Mist eliminator top vanes clean where top washed.	Run terminated as planned. Sulfate saturation 45% at a magnesium ion level of 3000 ppm. (a) Total stoich. ratio for Ca & Mg is 0.96-1.08 (Avg. alkali util. is 98 %).	Run terminated as planned. 20-25% of underside of mist eliminator area was 50-100% plugged with mud and scale. The underside of the mist eliminator top vanes had ~100 mils scale.

Table 5-1 (continued)

SUMMARY OF LIME RELIABILITY TESTS ON VENTURI/SPRAY TOWER SYSTEM

Run No.	619-1A	621-1A	622-1A	623-1A
Start-of-Run Date	12/19/74	1/18/75	1/30/75	3/12/75
End-of-Run Date	1/2/75	1/23/75	3/5/75	3/19/75
On Stream Hours	327	113	787	162
Gas Rate, acfm @ 330°F	25,000	25,000	25,000	25,000
Spray Tower Gas Vel, fps @ 125°F	6.7	6.7	6.7	6.7
Venturi/Spray Tower Liquor Rates, gpm	600/1200	600/1200	600/1200	600/1200
Spray Tower L/G, gal/mcf	60	60	60	60
Percent Solids Recirculated	7-10	8-9	7.2-8.8	7.4-8.9
Effluent Residence Time, min.	12	12	17	17
Solids Disposal System	Clarifier & Filter	Clarifier & Filter	Clarifier and Centrifuge (or filter)	Clarifier & Centrifuge
Stoichiometric Ratio, moles Ca added/mole SO_2 absorbed	1.07-1.23	1.20-1.27	1.26-1.30	1.07-1.17
Avg % Lime Utilization, 100x moles SO_2 abs./mole Ca added	87	81	88	89
Inlet SO_2 Concentration, ppm	1150-4000	1600-3600	2200-3900	2700-3[illegible]00
Percent SO_2 Removal	70-98	82-95	71-91	74-88
Scrubber Inlet pH Range	7.3-8.3	7.8-8.3	7.1-8.3	7.7-8.3
Scrubber Outlet pH Range	4.9-5.7	4.2-5.6	4.7-5.3	4.85-5.1
Percent Sulfur Oxidized	14-34	12-26	12-28	11-21
Loop Closure, % Solids Dischg.	53-60	57-61	50-62	53-60
Calculated % Sulfate Saturation in Scrubber Inlet Liquor @ 50°C	125	130	115	105
Dissolved Solids, ppm	6600-8000	4600-6500	6500-10,000	7000-8400
Total ΔP Range, Excluding Mist Eliminator, in. H_2O	10.8-12.0	11.3-12.0	11.1-12.5	11.4-11.7
Venturi ΔP, in. H_2O	9	9	9	9
Mist Eliminator ΔP, in. H_2O	0.60-1.10	0.63-0.70	0.20-0.30	0.17-0.20
Absorbent	Lime slurried to 20 wt % with makeup water and added to scrubber downcomer.	Lime slurried to 20 wt % with makeup water and added to scrubber downcomer.	Lime slurried to 20 wt % with makeup water and added to scrubber downcomer.	Lime slurried to 20 wt % with makeup water and added to scrubber downcomer.
Mist Eliminator	Bottom washed with makeup water at 2.6 gpm/ft² for ~8 min every 4 hrs. Total makeup ~5 gpm avg.	Bottom washed continuously at 0.69 gpm/ft² using a mixture of ~5 gpm fresh water and ~35 gpm clarified liquor.	Bottom washed with makeup water at 3.0 gpm/ft² for ~8 min every 4 hrs. Total makeup ~5 gpm avg.	Top washed sequentially with fresh water. Each nozzle (6 total) on 4 min (at 0.5 gpm/ft²) with 76 min off between nozzles. Bottom washed with remaining makeup at 3 gpm/ft² for ~3.5 min every 4 hrs.
Scrubber Internals	All nozzles on 4 headers sprayed downward. 7 nozzles/header on top 3 headers. 6 nozzles on bottom header.	All nozzles on 4 headers sprayed downward. 7 nozzles/header on top 3 headers. 6 nozzles on bottom header.	All nozzles on 4 headers sprayed downward. 7 nozzles/header on top 3 headers. 6 nozzles on bottom header.	All nozzles on 4 headers sprayed downward. 7 nozzles/header on top 3 headers. 6 nozzles on bottom header.
System Changes Before Start of Run	Mist eliminator cleaned in place. Effluent hold tank agitator raised to original level.	Mist eliminator removed and cleaned.	Installed new open-vane, horizontal mist eliminator at an elevation 1 foot higher than previous open-vane, horizontal mist eliminator.	Cleaned mist eliminator and outlet duct. Installed mist eliminator sequential topwash system.
Method of Control	Scrubber inlet pH controlled at 8.0±0.2.	Scrubber inlet pH controlled at 8.0±0.2.	Scrubber inlet pH controlled at 8.0±0.2.	Scrubber inlet pH controlled at 8.0±0.2.
Run Philosophy	Intended 2 wks. To observe the rate of scale buildup on sloped mist eliminator using an intermittant, high pressure fresh water bottom wash.	Intended 2 wks. To observe the rate of scale/solids buildup on the sloped mist eliminator washed with a continuous bottomwash using all available makeup water and clarified liquor.	Intended 2 wks. To establish base conditions for the performance of the new open-vane (of old design) mist eliminator with underside washing only.	Intended long term. To observe the rate of scale/solids buildup on the mist eliminator with bottom wash and sequential topwash.
Results	Run terminated as planned. The mist eliminator was 25-30% restricted but the test was invalid since 3 of the 9 mist eliminator underwash nozzles had lost alignment causing uneven wash coverage.	Run terminated as planned. Bottom of mist eliminator top vane coated with solids (60 mils avg.).	Run terminated as planned. Mist eliminator 5% restricted by scale and solids.	Run terminated in order to test higher gas velocities when inspection revealed the mist eliminator to be clean with only a light scattered dust on the mist eliminator vanes.

Table 5-1 (continued)

SUMMARY OF LIME RELIABILITY TESTS ON VENTURI/SPRAY TOWER SYSTEM

Run No.	624-1A	
Start-of-Run Date	3/19/76	
End-of-Run Date	4/23/76	
On Stream Hours	823	
Gas Rate, acfm @ 330°F	30,000	
Spray Tower Gas Vel, fps @ 125°F	8.0	
Venturi/Spray Tower Liquor Rates, gpm	600/1200	
Spray Tower L/G, gal/mcf	50	
Percent Solids Recirculated	7-10	
Effluent Residence Time, min.	17	
Solids Disposal System	Clarifier & Centrifuge	
Stoichiometric Ratio, moles Ca added/mole SO_2 absorbed	1.03-1.20	
Avg % Lime Utilization, 100x moles SO_2 abs./mole Ca added	90	
Inlet SO_2 Concentration, ppm	2250-3750	
Percent SO_2 Removal	70-87	
Scrubber Inlet pH Range	7.8-8.3	
Scrubber Outlet pH Range	4.8-5.2	
Percent Sulfur Oxidized	12-30	
Loop Closure, % Solids Dischg.	48-58	
Calculated % Sulfate Saturation in Scrubber Inlet Liquor @ 50°C	95	
Dissolved Solids, ppm	6000-10,000	
Total ΔP Range, Excluding Mist Eliminator, in. H_2O	12.0-12.6	
Venturi ΔP, in. H_2O	9	
Mist Eliminator ΔP, in. H_2O	0.25-0.35	
Absorbent	Lime slurried to 20 wt % with makeup water and added to scrubber downcomer.	
Mist Eliminator	Top washed sequentially with fresh water. Each nozzle (6 total) on 4 min (at 0.5 gpm/ft²) with 76 min off between nozzles. Bottom washed with remaining makeup at 3 gpm/ft² for ~4.1 min every 4 hrs.	
Scrubber Internals	All nozzles on 4 headers sprayed downward. 7 nozzles/header on top 3 headers. 6 nozzles on bottom header.	
System Changes Before Start of Run	No changes.	
Method of Control	Scrubber inlet pH controlled at 8.0±0.2.	
Run Philosophy	Attempt to operate at an increased gas velocity (8.0 vs 6.7 ft/sec).	
Results	Run terminated due to Boiler #10 routine maintenance outage. Mist eliminator 100 percent clean after 823 operating hours.	

5.1.1 Venturi/Spray Tower Run 609-1A

During previous reliability testing on the venturi/spray tower, deposits on the top vanes of the mist eliminator were observed at the end of each run. The mist elimination system consisted of a 316 stainless steel, 3-pass, open-vane, chevron mist eliminator with underside wash (see Figures 3-1 and 3-3).

Run 609-1A was begun on September 20, 1974 with a clean mist eliminator. The purposes of the test were to evaluate the effectiveness of topside washing on the mist eliminator and to determine the effect on scrubber liquor sulfate saturation of increasing the effluent residence time from 12 to 24 minutes.

The major test conditions selected were (see Table 5-1):

Spray tower gas velocity	6.7 ft/sec
Venturi liquid-to-gas ratio	30 gal/mcf
Spray tower liquid-to-gas ratio	60 gal/mcf
Percent solids recirculated	8
Effluent residence time	24 min
Scrubber inlet slurry pH (controlled)	8

During the test, the entire mist eliminator underside and a 14 ft^2 area[*] on the topside were washed at high pressure (45 psig) with makeup water at a rate of 2.7 gpm/ft^2 for the underside and 1.0 gpm/ft^2 for the topside for about 8 minutes every 4 hours.

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[*] Only a small section of the topside was washed because it was felt that entrainment from the top spray might overload the reheater and possibly allow moisture to reach the fan. In later tests, the entire topside was washed by resorting to sequential washing. Another possible solution would be to use a second mist eliminator to intercept entrainment from the topside sprays.

Run 609-1A was terminated as planned after 277 hours of operation. The topside spray had drastically reduced the scale* buildup on the top mist eliminator vanes. The washed area was essentially clean, with less than 1 mil of solids accumulation, compared with an average of 40 mils scale buildup on the rest of the topside surfaces. The bottom vanes held a white dust film that was easily rubbed off. This film has been observed in all runs with intermittent wash. The dust does not accumulate.

The beneficial effect of increased residence time in reducing the percent sulfate saturation was also observed. For this test with 24 minute effluent residence time, the calculated average sulfate saturation of the scrubber inlet liquor (see Table 5-1) was 110 percent compared with about 130 percent for Run 608-1A which had a 12 minute residence time. This effect of residence time is similar to that observed for limestone systems when supersaturated with respect to sulfate (see Reference 1).

5.1.2 Venturi/Spray Tower Run 610-1A

Run 610-1A was a short-term test to determine the effect of alkali addition to the effluent hold tank on the scrubber liquor sulfate saturation, as opposed to alkali addition to the scrubber downcomer (Run 609-1A). It had been proposed that lime addition to the downcomer would correspond to a small residence tank in series with the larger effluent hold tank resulting in reduced sulfate saturation. The run was started on October 2 and continued through October 13, 1974, for a total of 253 operating hours. The system was not cleaned before the test.

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*Unless otherwise noted, scale refers to hard crystalline sulfate solids. Solids or soft-solids refer to mud-like soft solids.

Inspection at the end of the run indicated formation of new scale on all surfaces in the spray tower below the mist eliminator. The top slurry spray header contained scale up to 60 mils, while scale thickness on the walls ranged from 25 mils in the area adjacent to the top header to 40 mils on the bottom of the tower. Several slurry nozzles were plugged and white scale covered most diffusers. Scale coverage on the wall areas above the mist eliminator was also observed. The venturi flooded elbow held new scale deposits on all walls.

The washed area of the top mist eliminator vanes was still clean after 530 operating hours (Runs 609-1A and 610-1A), compared with an average of 70 mils scale buildup on the rest of the topside vane surfaces. The mist eliminator bottom vanes held smooth white scale about 10 mils thick. The overall mist eliminator restriction had increased from 2 to 4 percent during this run.

For this run (lime added to the hold tank), the calculated sulfate saturation of the inlet scrubber liquor was 145 percent at an average inlet SO_2 concentration of 2800 ppm.* This value was about 35 percent higher than observed in Run 609-1A (lime added to the downcomer) at the same inlet SO_2 concentration. The results of these two tests, showing a decrease in sulfate saturation with lime addition to the downcomer, confirmed observations in earlier lime reliability tests (see Section 9.3, Reference 1).

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*Under the conditions for Run 610-1A, the scrubber inlet liquor sulfate saturation for a lime system is a strong function of the inlet gas SO_2 concentration (SO_2 absorption rate). A 100 ppm increase in SO_2 concentration corresponds roughly to a 10 percent increase in sulfate saturation (see Section 9-3, Reference 1).

5.1.3 Venturi/Spray Tower Run 611-1A

Results at the EPA pilot facility at Research Triangle Park, N.C., have shown that it is possible to operate lime wet-scrubbing systems with liquors unsaturated with respect to calcium sulfate, by addition of magnesium ion (MgO) to the scrubber liquor (see Reference 3). Run 611-1A was intended to verify these results at the Shawnee 10 Mw scale.

The test conditions for Run 611-1A differed from those of the previous Run 610-1A in four respects: (1) magnesium oxide was added to the process slurry in the effluent hold tank to maintain 3000 ppm Mg^{++} in the recirculated slurry, (2) the effluent residence time was reduced from 24 to 6 minutes (the agitator in the effluent hold tank had been lowered before the run started), (3) the scrubber inlet pH control point was dropped from 8.0 to 7.0, and (4) the lime addition point was relocated from the effluent hold tank to the scrubber downcomer.

In addition to the above changes, the 316 stainless steel, 3-pass, open-vane, horizontal chevron mist eliminator was replaced by a 316 stainless steel, 4-pass, closed-vane, sloped (cone-shaped) chevron mist eliminator (see Figure 3-3). The new sloped mist eliminator was believed to have better wash liquor draining characteristics, and hence less scaling and plugging potential. The underside of the sloped mist eliminator was washed continuously with approximately 40 gpm (0.69 gpm/ft^2) of diluted clarified liquor (about 5 gpm makeup water and about 35 gpm clarified liquor) at 20 psig pressure.

The run was started on October 25 and terminated, due to an unscheduled maintenance outage on boiler No. 10, on November 11, 1974, after a total of 392 operating hours. The system had been cleaned before the run was started.

Inspections were made after 47 and 250 operating hours and at the end of the run. The venturi section, flooded elbow, spray tower walls (both above and below the mist eliminator), and spray tower outlet duct were clean. Old scale deposits remaining after the previous cleaning had slowly disappeared. Scale deposits on the inlet vanes of the mist eliminator, ranging in thickness from 19 to 84 mils, were observed during the first inspection, but the scale had nearly disappeared by the end of the run. Channels along the lower edge of the mist eliminator not directly contacted by the wash spray were completely filled with soft solids. The underside of the outlet vanes were covered uniformly with 50 mils of soft fibrous solids.

Calculated average sulfate saturations of 45 percent for the scrubber inlet liquor and 95 percent for the scrubber outlet liquor confirmed that the system was operating unsaturated with respect to sulfate. The apparent descaling effect observed during the system inspections underscores the beneficial effect of unsaturated operation.

5.1.4 Venturi/Spray Tower Run 618-1A*

Run 618-1A was begun on November 21, 1974 and continued until December 2, 1974, for a total of 235 operating hours. The system, including the mist eliminator, had been cleaned before the start of the run.

The test was intended to be short term and was designed to observe the rate of scale buildup on the sloped chevron mist eliminator under a continuous 15 gpm (0.26 gpm/ft^2) fresh water underside wash corresponding to about three times the required makeup water rate.** The test conditions were chosen to permit a direct comparison with the scale buildup rate on the open-vane, horizontal chevron mist eliminator during Run 606-1A (see Table 5-1 and Reference 1).

Inspection after termination of the run revealed that 20 to 25 percent of the underside of the mist eliminator area was 50 to 100 percent plugged with a mixture of mud and scale. Also, the underside of the mist eliminator top vane had approximately 100 mils of scale buildup. The scale and solids buildup on the underside of the mist eliminator may have been due partly to insufficient coverage by the mist eliminator underspray. The average scale growth rate on the mist eliminator top vanes was 70 mils/week for this run as compared with 50 mils/week for the open-vane, horizontal chevron mist eliminator during Run 606-1A (see Reference 1)

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*Runs 612-1A through 617 were incomplete short-term factorial tests. They will be reported with the factorial tests scheduled for a later date.

**This test was run under open liquor loop conditions. The average percent solids in the discharge sludge was 18 percent.

The spray tower walls above the mist eliminator were clean, but below the mist eliminator the walls were covered with 120 mils of scale. The slurry nozzles had "whiskers" of white scale on the diffusers. The venturi section below the throat and the flooded elbow were covered with a hard, smooth 110-mil scale.

The calculated sulfate saturation was 140 percent for the scrubber inlet liquor and 170 percent for the scrubber outlet liquor. The unexpectedly high sulfate saturations observed during open loop operation may have been due to insufficient mixing in the effluent hold tank at low agitator position and high liquor level (17 minutes residence time at run start and 12 minutes after November 25). The scrubber inlet liquor pH control was also quite erratic throughout the run (see Appendix D, Figure D-4).

5.1.5 Venturi/Spray Tower Run 619-1A

Run 619-1A was begun on December 19, 1974 and continued until January 2, 1975, for a total of 327 operating hours. The run was intended to be short term in order to observe the rate of scale buildup on the sloped chevron mist eliminator using an intermittent underside wash for 8 minutes every 4 hours with 150 gpm (2.6 gpm/ft^2) of high pressure (45 psig) makeup water. Run conditions were chosen to enable a direct comparison with the scale buildup rate on the open-vane, horizontal chevron mist eliminator during Run 608-1A (see Table 5-1 and Reference 1). The mist eliminator had been cleaned in place prior to the start of the run.

The agitator, which had been lowered by 4 feet prior to Run 611-1A, was raised to its original position before the start of this run.

Inspection after termination of the run revealed that approximately 25 to 30 percent of the underside of the mist eliminator area was completely restricted by solids. Much of this plugging could be attributed to misorientation of three of the nine underside wash spray nozzles. About 150 mils of scale was deposited on the underside of the outlet vanes.

The average scale growth rate on the mist eliminator top vanes was about 75 mils/week for this run as compared with 25 mils/week for the open-vane, horizontal chevron mist eliminator during Run 608-1A.

The calculated average sulfate saturations were 125 and 145 percent for the scrubber inlet and outlet liquors, respectively.

5.1.6 Venturi/Spray Tower Run 621-1A*

Run 621-1A was started on January 18 and terminated on January 23, 1975, after 113 hours of operation. The purpose of the test was to study the rate of scale/solids buildup on the sloped mist eliminator operating with a continuous bottom wash using all available makeup water (~5 gpm) and clarified liquor (~35 gpm) at 16 psig nozzle pressure. Other test conditions were the same as for Run 619-1A. The mist eliminator was removed and cleaned prior to the startup.

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*Venturi/spray tower Run 620-1A was of a short duration due to operational difficulties with returning clarified liquor to the spray tower for mist eliminator washing.

Inspection at the end of the run indicated that, in general, the continuous underspray with a mixture of makeup water and clarified liquor was not effective in preventing solids deposition in the mist eliminator. Large areas were 25 to 50 percent restricted with soft solids. The outlet vanes contained 2 to 3 mils of dust while the middle vanes were covered with light scattered dust deposits.

It was felt that improved design of the spray system combined with proper wash rate and cycle would reduce the rate of solids accumulation in the sloped chevron mist eliminator. However, because of the complexity in the geometry of the sloped mist eliminator and the low probability that it would become a representative design for a full scale scrubber, it was decided to abandon further testing of this mist eliminator in the spray tower. The sloped mist eliminator was removed and a new 316 stainless steel, 3-pass, open-vane, horizontal chevron mist eliminator was installed (see Figure 3-3).*

Due to the short duration of this run, no representative liquor samples could be obtained, and hence no percent sulfate saturations are reported.

5.1.7 Venturi/Spray Tower Run 622-1A

Run 622-1A was begun on January 30 and terminated on March 5, 1975, for a total of 787 operating hours. The run was intended to establish base conditions, in terms of reliability and operability, for the new open-vane, horizontal chevron mist eliminator.

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*Since the original mist eliminator used prior to Run 611-1A was in poor physical condition due to corrosion and wear, an identical one was fabricated and installed. The new mist eliminator was installed at an elevation one foot higher than the old one.

The underside of the mist eliminator was washed intermittently with high pressure (45 psig) water at 150 gpm (3 gpm/ft^2) for about 8 minutes every 4 hours. The effluent residence time was increased from 12 to 17 minutes for this run.

Inspections were made at 110, 275, and 574 hours and at the end of the run after 787 hours. Solids deposits that restricted the mist eliminator by 3 percent were noted at the second inspection. By the end of the run, the overall restriction of the mist eliminator by scale and solids had increased from 3 to 5 percent. The top surface of the top vanes was coated with scale which averaged 60 mils thick. A small area held scale and solids up to 0.5 inch thick on the underside trailing edge of the top vanes. The middle and bottom vanes held light, scattered dust about 2 mils thick. The spray tower had less scale in the lower third of the vessel than it had at the end of the previous run. The solids deposit on the duct walls between the reheater and fan dampers averaged 150 mils thick. The dampers were clean, but the fan blades had deposits 60 to 70 mils thick. The venturi section was generally clean.

The calculated average sulfate saturation was 115 percent for the scrubber inlet liquor and 135 percent for the scrubber outlet liquor. These values are 10 percent lower than for Run 619-1A even though the chloride concentration was about 1000 ppm higher and the inlet gas SO_2 concentration was about 400 ppm higher. This drop in saturation is attributed to higher effluent residence time, i.e., 17 minutes for this run versus 12 minutes for Run 619-1A.

5.1.8 Venturi/Spray Tower Run 623-1A

Run 623-1A was started on March 12 and terminated on March 19, 1975, after 162 hours of operation. The purpose of this run was to test the effectiveness of a sequential top side wash system on the open-vane, horizontal mist eliminator. Earlier tests (Runs 609-1A and 610-1A) had shown that washing a small area of the topside of the mist eliminator, in combination with the full underside washing, was very effective in keeping the washed area clean.

The sequential topside wash system operated with 6 spray nozzles on a 4 minute "on", 76 minute "off" time cycle, with only one nozzle activated during each "on" cycle. This arrangement resulted in a total 8 hour cycle time for the 6 nozzles. The fresh water flow rate through one nozzle during the "on" cycle was set at 8 gpm (at 13 psig), covering 16 ft^2 to give a specific spray rate of 0.5 gpm/ft^2.

In addition to the sequential topside wash, the entire underside of the mist eliminator was washed with the remaining makeup water at 150 gpm (3 gpm/ft^2) at 45 psig for about 3.5 minutes every 4 hours. The "on" cycle was never allowed to drop below 2 minutes at any time.

The system had been cleaned before the run was started. Inspection of the mist eliminator at the end of the run showed that the combination of sequential topside wash and intermittent underside wash was successful in preventing scale and solids accumulation on the mist eliminator. Only scattered dust a few mils thick was formed on some of the vanes. Wall areas above the mist eliminator held only scattered light dust with light scale in some areas. The walls below the mist eliminator were unchanged since startup. The vessel bottom was clean.

The calculated average sulfate saturations for the scrubber inlet and outlet liquors were 105 and 130 percent, respectively.

5.1.9 Venturi/Spray Tower Run 624-1A

The combination of sequential topside and intermittent underside wash had been successful in keeping the mist eliminator free of scale and solids accumulation at 6.7 ft/sec gas velocity during Run 623-1A. Run 624-1A was started on March 19, 1975, without system cleaning, to test the mist elimination system at a higher gas velocity of 8.0 ft/sec. For this run, the average wash time for the underside of the mist eliminator was increased from 3.5 to 4.3 minutes every 4 hours because of the higher makeup water rate available at the higher gas velocity. The wash rate and cycle for the topside were the same as for Run 623-1A.

Run 624-1A was terminated on April 23, 1975, after 823 hours of operation due to a scheduled maintenance outage on boiler No. 10.

A total of 4 inspections were made for this run, including one at the end of the run. The mist eliminator was found to be free of any restriction during each of these inspections. Vane surfaces washed earlier in the wash cycle usually held 2 mils of scattered white dust, while recently washed vane surfaces were entirely clean.

Both the piping for the mist eliminator topside spray and the corrosion specimen rack above the mist eliminator were coated with dust. Some scale was noticed on parts of the spray tower wall above the mist eliminator and scale up to 1 inch thick encircled the spray tower outlet duct. The spray tower wall below the top slurry spray header had less old scale. The venturi section was almost clean and no solids had formed in the flooded elbow.

The calculated average sulfate saturations were 95 and 120 percent for the scrubber inlet and outlet liquors, respectively. The low sulfate saturations may have been caused by the lower liquid-to-gas ratio at the higher gas velocity of 8.0 ft/sec (see TCA Runs 539-2A through 543-2A and Run 545-2A, Section 6.1).

5.2 MATERIAL BALANCES

The results of calcium and sulfur material balances for venturi/spray tower lime reliability Runs 610-1A and 624-1A are summarized in Table 5-2. The computed inlet and outlet rates for calcium and sulfur are in good agreement. This is consistent with results of earlier lime reliability tests (see Reference 1).

The absorbed SO_2 was computed from the measured inlet gas rate, the inlet and outlet gas SO_2 concentrations, and the estimated gas outlet rate. The added calcium was computed from the measured volumetric rate of limestone slurry additive and the solids concentration in the slurry. The discharged sulfur and calcium were computed from the measured rate of slurry discharged from the system and the concentrations of sulfur and calcium in the discharge. Details of the calculation procedure are given in Reference 1.

Table 5-2

SUMMARY OF MATERIAL BALANCES FOR SULFUR AND CALCIUM FROM LIME RELIABILITY TESTS

Run No.	Material Balance Period, hours	Sulfur Balance			Calcium Balance			Average Stoichiometric Ratio, Moles Ca Added/Mole SO_2 Absorbed	
		SO_2 Absorbed, lb-moles/hr	SO_x in Slurry Discharged, lb-moles/hr	Percent Error	Ca in Lime Feed, lb-moles/hr	Ca in Slurry Discharged, lb-moles/hr	Percent Error	Based on Lime Added and SO_2 Absorbed	Based on Slurry Analysis
610-1A	166	6.3	7.0	+10	6.1	8.3	+26	0.97	1.19
624-1A	165	7.4	8.6	+14	7.9	9.5	+17	1.07	1.10

5.3 CONCLUSIONS

5.3.1 Scrubber Operation

As with limestone testing, earlier lime reliability test results have shown that scrubber internals can be kept relatively free of sulfate (gypsum) scale if the sulfate saturation of the scrubber liquor is kept below the critical value of about 135 percent (Section 7.3, Reference 1). As with limestone, this can be accomplished with increased percent solids recirculated (Run 603-1A versus 601-1A) and/or with increased effluent residence time (Run 622-1A versus 619-1A). Lime tests have further shown that lime addition to the scrubber downcomer, corresponding to a small residence tank in series with the larger effluent hold tank, can substantially reduce the sulfate saturation (Run 609-1A versus 610-1A). This permits operation at reduced solids concentration and/or effluent residence time.

Run 611-1A has confirmed the findings at the EPA pilot facility that the scrubber can be operated unsaturated with respect to sulfate by the addition of magnesium ion (MgO) to the process slurry. Under the conditions tested, the average sulfate saturation was 45 percent for the scrubber inlet and 95 percent for the scrubber outlet liquor, with about 3000 ppm Mg^{++} concentration in the recirculated slurry. Gypsum scale, present prior to start-up, dissolved during the run.

As in earlier tests, the lime test results have shown that the sulfate saturation of the scrubber inlet liquor is a strong function of the inlet gas SO_2 concentration (SO_2 absorption rate). The data have indicated that a 100 ppm increase in SO_2 inlet concentration corresponds roughly to a 10 percent increase in sulfate saturation at the run conditions tested.

It should be noted that the 27 full-cone, spiral-tipped Bete nozzles in the spray tower have shown no signs of measurable erosion on the stellite tips after approximately 7200 hours in 8 percent slurry service at 10 psig nozzle pressure.

5.3.2 Mist Eliminator Operation

Significant improvement in the operation of the 316 stainless steel, 3-pass, open-vane, horizontal chevron mist eliminator has been achieved during this report period. During the earlier lime reliabilty testing (see Reference 1), scale and solids accumulation occurred mostly on the top surfaces of the mist eliminator when it was washed only from the underside. With sequential topside and intermittent underside washing, the mist eliminator was essentially clean after 162 hours of operation at 6.7 ft/sec gas velocity during Run 623-1A, and again after 823 hours of operation at 8.0 ft/sec during Run 624-1A. The mist eliminator was not cleaned between the two runs. Future tests with this mist elimination system will include gas velocities greater than 8.0 ft/sec and lower wash water flow rate.

Operations with the 316 stainless steel, 4-pass, closed-vane, sloped (cone-shaped) chevron mist eliminator have not been successful (Runs 611-1A, 618-1A, 619-1A, and 621-1A). It is felt that improved design of the spray system, in combination with proper wash rate and cycle, would reduce or eliminate the scale and solids accumulation within the sloped mist eliminator. However, because of the complexity in the geometry of this cone-shaped mist eliminator and the low probability that it would become a representative mist eliminator design for a full scale scrubber unit, it was decided to abandon further testing of this unit in the spray tower.

Section 6

TCA LIMESTONE RELIABILITY TEST RESULTS

Performance and analytical data from limestone reliability testing on the TCA system from October 1974 through April 1975 are presented in this section, along with an evaluation of each test and the conclusions drawn, to date. Results of limestone reliability tests prior to October 1974 have been reported in Reference 1.

6.1 PERFORMANCE DATA AND TEST EVALUATION

A summary of the test conditions and results of limestone reliability tests on the TCA system is presented in Table 6-1.* Properties of coal and limestone used during the tests can be found in Appendix C. Selected operating data for tests which lasted more than one week are presented graphically in Appendix F. Average scrubber and Koch tray liquor analytical data and the corresponding calculated percent sulfate (gypsum) saturations are presented in Appendix G. An evaluation and discussion of each test is presented in the following sections.

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*Limestone reliability runs made prior to October 1974 have been included in this table.

Table 6-1

SUMMARY OF LIMESTONE RELIABILITY TESTS ON TCA SYSTEM

Run No.	525-2A	526-2A	527-2A	528-2A
Start-of-Run Date	10/24/73	11/21/73	1/18/74	2/5/74
End-of-Run Date	11/15/73	1/10/74	1/24/74	2/26/74
On Stream Hours	517	1190	133	424
Gas Rate, acfm @ 300°F	25,000	20,900	20,500	20,400
Gas Velocity, fps @ 125°F	10.5	8.6	8.6	8.6
Liquor Rate, gpm	1200	1200	1200	1200
L/G, gal/mcf	60	73	73	73
Percent Solids Recirculated	14-16	14-15.5	15-16	14-16
Effluent Residence Time, min.	10	10	10	12
Stoichiometric Ratio, moles Ca added/mole SO_2 absorbed	1.2-1.6	1.3-1.7	1.5-1.9	1.1-1.45
Avg % Limestone Utilization, 100x moles SO_2 abs./mole Ca added	71	69	57	78
Inlet SO_2 Concentration, ppm	1800-4000	1600-4300	2600-3800	2000-4000
Percent SO_2 Removal	73-88	75-87	75-85	70-90
Scrubber Inlet pH Range	5.5-6.1	5.65-5.9	5.75-5.9	5.7-5.95
Scrubber Outlet pH Range	5.2-5.8	5.1-5.5	5.3-5.5	5.2-5.5
Percent Sulfur Oxidized	15-30	15-35	15-35	10-30
Solids Disposal System	Clarifier	Clarifier	Clarifier	Clarifier
Loop Closure, % Solids Dischg.	31-42	35-47	34-39	25-33
Calculated % Sulfate Saturation in Scrubber Inlet Liquor @ 50°C	140	130	130	110
Total Dissolved Solids, ppm	7800-9600	7800-9700	7700-8900	6200-6800
Total ΔP Range Excluding Mist Eliminator and Koch Tray, in. H_2O	5.5-6.5	6.3-6.7	6.6-6.9	4.9-5.3
Mist Eliminator and Koch Tray ΔP Range, in. H_2O	2.3-2.7 (10/24-11/12) 2.7-3.1 (11/12-11/15)	1.9-2.1	2.1-3.1	2.0-2.2
Mist Eliminator ΔP Range, in. H_2O	--	0.15-0.26	0.30-1.00	0.16-0.20
Absorbent	Limestone slurried to 60 wt % with makeup water and added to EHT.	Limestone slurried to 60 wt % with makeup water and added to EHT.	Limestone slurried to 60 wt % with makeup water and added to EHT.	Limestone slurried to 60 wt % with makeup water and added to EHT.
Mist Eliminator/Koch Tray	No mist eliminator wash. K.T. (2" weir height) irrigated with available makeup water (~9 gpm) and all available clarified liquor (~15 gpm). Bottom of Koch tray steam sparged 1 min/hr.	No mist eliminator wash. K.T. (2" weir height) irrigated with available makeup water (~8 gpm) and all available clarified liquor (~15 gpm). Bottom of Koch tray steam sparged 1 min/hr.	No mist eliminator wash. K.T. (3" weir height) irrigated with available makeup water (~7 gpm) and all available clarified liquor (~15 gpm). Was not irrigated for 2 hr period. Bottom of Koch tray steam sparged 1 min/hr.	No mist eliminator wash. K.T. (2" weir height) irrigated open-loop (once-through) with 25 gpm raw water only. Bottom of Koch tray steam sparged 1 min/hr.
Scrubber Internals	3 beds (4 grids) with 5" spheres/bed. Top bed-new TPR spheres. Middle & bottom-new HDPE spheres.	3 beds (4 grids) with 5" spheres/bed. Top bed-new HDPE spheres. Middle & bottom-worn HDPE's from previous run.	2 beds (3 grids) with 7 1/2" spheres/bed. Top bed- 5" worn + 2 1/2" new HDPE spheres. Bottom bed-new HDPE's. Slurry nozzles not used (open pipe only) for this run only.	3 beds (4 grids) with 5" spheres/bed. All beds-new TPR spheres.
System Changes Before Start-of-Run	System (scrubber, Koch tray, and mist eliminator) cleaned.	System cleaned. Replaced top bed spheres with new HDPE spheres. PWHT outlet (Koch tray inlet) pump switched from Centriseal to Hydroseal.	System not cleaned. Removed top grid and bed of spheres. Middle bed-5" HDPE spheres from top bed + 2 1/2" new HDPE's. Bottom bed-7 1/2" new HDPE's. Removed inlet slurry nozzles. Increased Koch tray weir height to 3".	System cleaned. Returned to 3 beds (4 grids) with 5" new TPR spheres/bed. Reinstalled inlet slurry nozzles. Installed Elliot strainer on scrubber loop. Decreased Koch tray weir height to 2".
Method of Control	SO_2 removal controlled at 84±2%	SO_2 removal controlled at 84±2%	SO_2 removal controlled at 84±2%	SO_2 removal controlled at 84±2% Overrides: Inlet pH ≤ 5.95 Stoich. Ratio ≤ 1.65
Run Philosophy	Intended long-term. Conditions chosen for long-term reliability based on reliability verification tests.	Intended long-term. Velocity reduced for reliability. HDPE spheres to be used until strainers are installed on scrubber loop.	Intended short-term. To determine whether changes in scrubber internal configuration could reduce slurry solids carryover.	Intended 3 wks. To observe any effect on mist eliminator solids and scale deposits with raw water only for Koch tray irrigation.
Results	Terminated due to rapidly increasing pressure drop across mist elim. and Koch tray. Large solids deposits on underside of Koch tray and on scrubber walls between tray and main slurry header. TPR half-spheres plugged inlet slurry nozzles (believed to be primary problem). Scrubber stages scale-free. Bottom of mist eliminator 10% plugged.	Terminated to replace worn HDPE spheres with new HDPE spheres. Some solids accumulation between slurry nozzles and Koch tray (due to partial pluggage of spray nozzles with foreign materials). Bottom of mist eliminator 15% plugged.	Inconclusive. Solids carryover to Koch tray and mist eliminator appeared equal to or greater than previous run. Bottom of mist eliminator 65% plugged.	Mist eliminator and Koch tray areas clean. Due to less tight liquor loop from weepage of Koch tray raw water, calculated sulfate saturation was slightly lower at 110%.

Table 6-1 (continued)

SUMMARY OF LIMESTONE RELIABILITY TESTS ON TCA SYSTEM

Run No.	529-2A	530-2A	531-2A	532-2A
Start-of-Run Date	2/26/74	3/28/74	5/10/74	7/17/74
End-of-Run Date	3/7/74	4/17/74	6/26/74	7/29/74
On Stream Hours	213	476	1088	258
Gas Rate, acfm @ 300°F	20,900	20,900	20,900	20,900
Gas Velocity, fps @ 125°F	8.6	8.6	8.6	8.6
Liquor Rate, gpm	1200	1200	1200	1700
L/G, gal/mcf	73	73	73	104
Percent Solids Recirculated	14.5-16	14-16	7-9	7-9
Effluent Residence Time, min.	12	12	12	12
Stoichiometric Ratio, moles Ca added/mole SO_2 absorbed	1.15-1.35	1.2-1.55	1.3-1.7 (5/10-26, 6/19-26) 1.0-1.2$^{(a)}$ (5/26-6/19)	0.88-1.20$^{(b)}$
Avg % Limestone Utilization, 100x moles SO_2 abs./mole Ca added	80	73	67 (5/10-26, 6/19-26) 91$^{(a)}$ (5/26-6/19)	93$^{(b)}$
Inlet SO_2 Concentration, ppm	2300-3900	2200-4200	1750-3750	2000-3900
Percent SO_2 Removal	79-89	78-89	71-96	96-99
Scrubber Inlet pH Range	5.7-5.9	5.75-5.95	5.4-6.1	5.6-6.0
Scrubber Outlet pH Range	5.2-5.5	5.1-5.4	4.7-5.5	5.2-5.6
Percent Sulfur Oxidized	15-30	12-29	13-40	7-25
Solids Disposal System	Clarifier	Clarifier (Centrifuge only after 4/10)	Clarifier	Clarifier
Loop Closure, % Solids Dischg.	30-47	30-43	35-42	32-43
Calculated % Sulfate Saturation in Scrubber Inlet Liquor @ 50°C	130	120	100	140
Total Dissolved Solids, ppm	8400	6300-8600	25,000	45,000-60,000
Total ΔP Range Excluding Mist Eliminator and Koch Tray, in. H_2O	4.9-5.3	4.8-5.1	4.3-6.6	4.5-4.8
Mist Eliminator and Koch Tray ΔP Range, in. H_2O	1.9-2.1	1.9-2.1	2.1-3.7	1.95-2.1
Mist Eliminator ΔP Range, in. H_2O	0.19-0.23	0.17-0.24	0.19-0.35	0.15-0.19
Absorbent	Limestone slurried to 60 wt % with makeup water and added to EHT.	Limestone slurried to 60 wt % with clarified process liquor and added to EHT.	Limestone slurried to 60 wt % with clarified process liquor and added to EHT.	Limestone slurried to 60 wt% with clarified process liquor and added to EHT.
Mist Eliminator/Koch Tray	No mist eliminator wash. K. T. (2" weir height) irrigated with available makeup water (~5 gpm) and all available clarified liquor (~15 gpm). Bottom of Koch tray steam sparged 1 min/hr.	No mist eliminator wash. K. T. (2" weir height) irrigated with 8 gpm makeup water and 7 gpm clarified liquor. Bottom of Koch tray steam sparged 1 min/hr.	No mist eliminator wash. K. T. (3" weir height) irrigated with available makeup water (~9 gpm) and all available clarified liquor (~30 gpm). Bottom of Koch tray steam sparged 1 min/hr.	Recycle loop around mist eliminator/K. T. Bottom of mist elim. washed with 8 gpm makeup water plus 7 gpm recycle liquor. K. T. (2" weir ht.) irrigated with ~15 gpm recycle liquor (plus 15 gpm mist elim. wash). Bottom of K. T. steam sparged 1 min/hr.
Scrubber Internals	3 beds (4 grids) with 5" spheres/bed. All beds-worn TPR spheres from previous run.	3 beds (4 grids) with 5" spheres/bed. All beds-worn TPR spheres from previous run.	3 beds (4 grids) with 5" spheres/bed. All beds-worn TPR spheres from previous run.	3 beds (4 grids) with 5" spheres/bed. All beds-worn TPR spheres from previous run.
System Changes Before Start-of-Run	No cleaning. No changes.	System cleaned. Koch tray periphery sealed. PWHT outlet (Koch tray inlet) pump converted from Hydroseal to Centriseal. Provided clarified liquor for limestone slurry feed tank. Modified piping to obtain constant Koch tray makeup water/liquor ratio. Sealed top of EHT.	System cleaned. Installed MgO add'n system. Lowered spray header 4'. Leveled Koch tray and further sealed periphery. Increased weir height to 3". Installed inlet weir. EHT overflow line blanked.	System cleaned. Provided for closed-circuit recycle loop around mist eliminator/Koch tray, including mist eliminator underwash. Lowered weir height to 2". EHT and PWHT sealed with CO_2 gas purge.
Method of Control	SO_2 removal controlled at: 84±2% Overrides: Inlet pH ≤ 5.95 Stoich. Ratio ≤ 1.65	SO_2 removal controlled at: 84±2% Overrides: Inlet pH ≤ 5.95 Stoich. Ratio ≤ 1.65	SO_2 removal controlled at: 5/10-5/23 84±2% 5/23-6/5 78±2% 6/5-6/19 84±2% 6/19-6/26 94±2%	Scrubber inlet pH controlled at 5.8±0.2
Run Philosophy	Intended long-term. Test conditions same as previous run, except Koch tray irrigated with all available makeup water and clarified liquor.	Intended long-term. EHT sealed to reduce oxidation, and Koch tray wash ratio held constant to observe any effect on solids buildup.	Intended long-term. Attempt to operate unsaturated with MgO add'n to sealed EHT. Percent solids lowered to 8% to provide additional clarifier liquor for Koch irrigation.	Intended long-term. Attempt to operate unsat. with MgO add'n to EHT (10,000 ppm Mg). 1700 gpm liquor rate, EHT & PWHT CO_2 blanket, mist elim. wash & mist elim/Koch tray recycle loop.
Results	Routine inspection after 213 hours revealed some soft solids and slight scale buildup on the mist elim. lower vanes. Although amount of scale and solids was slight, it was considered to be significant after only 213 hours, and run was terminated. Bottom of mist eliminator 10% plugged.	Unable to significantly reduce oxidation or sulfate saturation. Run terminated due to heavy scale and solids deposits on top of Koch tray, possibly caused by low (15 gpm) Koch tray flush rate and a clarifier rake malfunction on April 8 - 10, resulting in abnormal solids carry-over to Koch tray. Bottom of mist eliminator 44% plugged.	Unable to maintain unsaturated sulfate operation with 5000 ppm Mg. Steady state operation was not reached. Run terminated due to solids and scale buildup on mist eliminator, Koch tray and bottom grid. Bottom of mist eliminator 75% plugged. (a) Total stoich. ratio for Ca & Mg is 1.08-1.28 (avg. alkali util. 85%).	Unable to attain unsaturated sulfate operation with 10,000 ppm Mg. Run terminated due to scale build-up on Koch tray and loss of 4000 (~1/2 bed) spheres through grids. Bottom of mist eliminator 1-2% plugged. (b) Total stoich. ratio for Ca & Mg is 1.05-1.44 (avg. alkali util. is 80%).

Table 6-1 (continued)

SUMMARY OF LIMESTONE RELIABILITY TESTS ON TCA SYSTEM

Run No.	533-2A	534-2A	535-2A	535-2B
Start-of-Run Date	8/6/74	9/3/74	9/12/74	12/4/74
End-of-Run Date	8/21/74	9/8/74	12/4/74	12/30/74
On Stream Hours	332	100	1835	490
Gas Rate, acfm @ 300°F	20,900	20,400	20,500	20,400
Gas Velocity, fps @ 125°F	8.6	8.6	8.6	8.6
Liquor Rate, gpm	1200	1200	1200	1200
L/G, gal/mcf	73	73	73	73
Percent Solids Recirculated	14.5-15.5	10-12.5	12-14	9-16
Effluent Residence Time, min.	12	12	12(9/12-9/27), 15(after 9/27)	15(12/4-12/16), 25(after 12/16)
Stoichiometric Ratio, moles Ca added/mole SO_2 absorbed	0.86-1.31(a)	1.10-1.30	1.35-1.70	1.15-1.55
Avg % Limestone Utilization, 100x moles SO_2 abs./mole Ca added	92(a)	82	65	74
Inlet SO_2 Concentration, ppm	2000-3750	2700-3600	2000-4000	1900-4900
Percent SO_2 Removal	95-99	75-90	75-88	66-94
Scrubber Inlet pH Range	5.7-6.0	5.65-5.85	5.7-6.1	5.8-6.1
Scrubber Outlet pH Range	5.3-5.65	5.2-5.4	5.1-5.8	5.2-5.9
Percent Sulfur Oxidized	15-23	15-30	10-28	10-30
Solids Disposal System	Clarifier	Clarifier	Clarifier	Clarifier
Loop Closure, % Solids Dischg.	29-38	30-40	35-42	34-42
Calculated % Sulfate Saturation in Scrubber Inlet Liquor @ 50°C	135	130	115 (9/12-10/23), 105 (after 10/23)	125
Total Dissolved Solids, ppm	53,000-58,000	7900-8500	4000-8000	4500-7300
Total ΔP Range Excluding Mist Eliminator and Koch Tray, in. H_2O	4.6-4.9	4.3-4.35	4.0-4.6	3.8-5.0
Mist Eliminator and Koch Tray ΔP Range, in. H_2O	2.0-3.8	1.8-2.0	1.9-2.0	1.8-2.2
Mist Eliminator ΔP Range, in. H_2O	0.17-0.25	0.15-0.20	0.10-0.20	0.15-0.20
Absorbent	Limestone slurried to 60 wt% with clarified process liquor and added to EHT.	Limestone slurried to 60 wt% with clarified process liquor and added to EHT.	Limestone slurried to 60 wt% with clarified process liquor and added to EHT (9/12-11/25) and to downcomer after 11/25.	Limestone slurried to 60 wt % with clarified process liquor and added to downcomer (12/4-12/19 and to EHT (after 12/19)
Mist Eliminator/Koch Tray	Recycle loop around mist eliminator/K.T. Bottom of mist elim. washed with 8 gpm makeup water plus 7 gpm recycle liquor. K.T. (2" weir ht.) irrigated with 35 gpm recycle liquor (plus 15 gpm mist elim. wash). Bottom of K.T. steam sparged 1 min/hr.	Bottom of mist elim. washed cont. with 15 gpm dil. clar. liq. (~8 gpm makeup water + ~7 gpm clar. liq.). K.T. (2" weir ht.) irrig. with ~8 gpm clar. liq. + 15 gpm mist elim. wash. Bottom of Koch tray steam sparged 1 min/hr.	Bottom of mist elim. washed cont. with 15 gpm dil. clar. liq. (~9 gpm makeup water + ~6 gpm clar. liq.). K.T. irrig. with ~9 gpm clar. liq. + 15 gpm mist elim. wash. Total clar. liq. to mist elim. & K.T. 15 gpm min. Bottom of Koch tray steam sparged 1 min/hr.	Bottom of mist elim. washed cont. with 15 gpm dil. clar. liq. (~9 gpm makeup water + ~6 gpm clar. liq.). K.T. irrig. with ~9 gpm clar. liq. + 15 gpm mist elim. wash. Total clar. liq. to mist elim. & K.T. 15 gpm min. Steam sparging discontinued after 12/11.
Scrubber Internals	3 stages (4 grids) with 5 inches spheres/stage. All beds-new TPR sphers.	3 stages (4 grids) with 5 inches spheres/stage. All beds-worn TPR spheres from previous run.	3 stages (4 grids) with 5 inches spheres/stage. All beds-worn TPR spheres from previous run.	3 stages (4 grids) with 5 inches spheres/stage. All beds-worn TPR spheres from previous run.
System Changes Before Start-of-Run	System cleaned. Replaced worn TPR spheres with new TPR's.	System cleaned.	System cleaned. Seal water removed from cooling spray pump. Wall wash nozzles (4) to wash walls between slurry spray header and bottom of Koch tray installed during Boiler #10 outage (10/23-10/25).	Removed steam sparger (12/11). Wall wash nozzles (4) replaced by single K.T. underwash nozzle (12/23).
Method of Control	Scrubber inlet pH controlled at 5.8±0.2	Scrubber inlet pH controlled at 5.8±0.2	SO_2 removal controlled at 84±2%. Overrides: Inlet pH ≤ 6.0 Stoich. Ratio ≤ 1.6	SO_2 removal controlled at 84±2%. Overrides: Inlet pH ≤ 6.0 Stoich. Ratio ≤ 1.6
Run Philosophy	Intended long-term. Attempt to operate unsat. with 10,000 ppm Mg conc. in EHT. 1200 gpm liquor rate, 15% solids. CO_2 blanket over EHT & PWHT, and mist elim./KT recycle loop.	Intended long-term. Discontinue use of MgO. Test conditions chosen similar to 526-2A.	Intended long-term. Test conditions chosen similar to 526-2A.	Attempt to run at Run 535-2A conditions with intermittant burning of Montana low sulfur coal in Boiler #10.
Results	Unable to attain unsaturated sulfate operation with 10,000 ppm Mg. Run terminated due to scale build-up on Koch tray and mist eliminator. Bottom of mist eliminator 12% plugged. (a) Total stoich. ratio for Ca & Mg is 1.03-1.48 (Avg. alkali util. 80%).	Run terminated due to scale build-up on the Koch tray. Bottom of mist eliminator 1-2% plugged.	Run arbitrarily terminated prior to introduction of Montana low sulfur coal into boiler No. 10 and resultant operational difficulties. Inspection of system at 1835 hrs showed mist eliminator and Koch tray to be essentially clean (mist eliminator <4% plugged). Wall sprays kept wall area and bottom of the Koch tray clean.	Run terminated as planned. Inspection of system after 2325 hrs (535-2A plus 535-2B) showed mist eliminator bottom to be 8-9% plugged with flyash. The top of the Koch tray was 10% covered with scattered scale ~15 mils thick.

Table 6-1 (continued)

SUMMARY OF LIMESTONE RELIABILITY TESTS ON TCA SYSTEM

Run No.	536-2A	537-2A	538-2A	539-2A
Start-of-Run Date	12/31/74	1/15/75	1/24/75	3/7/75
End-of-Run Date	1/15/75	1/21/75	2/21/75	3/21/75
On Stream Hours	328	137	662	278
Gas Rate, acfm @ 330°F	24,000	24,000	24,000	28,800
Gas Velocity, fps @ 125°F	10.0	10.0	10.0	12.0
Liquor Rate, gpm	1200	1400	1400	1000
L/G, gal/mcf	62	73	73	43
Percent Solids Recirculated	13-16	12.5-14	12.9-17.5	13.0-17.0
Effluent Residence Time, min.	20	20	20	25
Stoichiometric Ratio, moles Ca added/mole SO_2 absorbed	1.2-1.6	1.3-1.6	1.3-1.6	1.5-1.7
Avg % Limestone Utilization, 100x moles SO_2 abs./mole Ca added	71	69	69	62
Inlet SO_2 Concentration, ppm	1250-4250	2000-3500	2000-4200	2000-3900
Percent SO_2 Removal	68-92	80-93	81-95	82-92
Scrubber Inlet pH Range	5.8-6.0	5.8-6.0	5.8-6.0	5.9-6.1
Scrubber Outlet pH Range	5.4-5.6	5.4-5.5	5.45-5.65	5.6-5.8
Percent Sulfur Oxidized	6-30	12-26	10-30	10-22
Solids Disposal System	Clarifier	Clarifier	Clarifier	Clarifier & Filter
Loop Closure, % Solids, Dischg.	32-43	33-40	31-40	~40
Calculated % Sulfate Saturation in Scrubber Inlet Liquor @ 50°C	100	125	100	25
Total Dissolved Solids, ppm	4200-6500	6000-7000	4400-7400	3000-5000
Total ΔP Range Excluding Mist Eliminator and Koch Tray, in. H_2O	5.2-5.6	5.8-6.45	5.6-7.0	6.7-6.85
Mist Eliminator and Koch Tray ΔP Range, in. H_2O	2.7-4.0	4.1-4.95	2.1-2.5	2.8-3.65
Mist Eliminator ΔP Range, in. H_2O	0.30-0.40	0.40-0.55	0.15-0.25	0.33-0.50
Absorbent	Limestone slurried to 60 wt % with clarified process liquor and added to EHT.	Limestone slurried to 60 wt % with clarified process liquor and added to EHT.	Limestone slurried to 60 wt % with clarified process liquor and added to EHT.	Limestone slurried to 60 wt % with clarified process liquor and added to EHT.
Mist Eliminator/Koch Tray	Bottom of mist elim. washed cont. with constant 15 gpm diluted clar. liq. (all makeup plus necessary clar. liq). Corresponds to 0.3 gpm/ft^2. Koch tray (2" weir ht.) irrig. with remaining clar. liq. Clar. liq. return 15 gpm minimum.	Bottom of mist eliminator washed continuously with constant 20 gpm (0.4 gpm/ft^2) diluted clarified liquor (all makeup plus necessary clarified liquor). Koch tray (2" weir ht.) irrigated with remaining clarified liquor. Clar. return 17 gpm minimum.	Bottom of mist eliminator washed continuously with constant 20 gpm (0.4 gpm/ft^2) diluted clarified liquor (all makeup plus necessary clarified liquor). Koch tray (2" weir ht.) irrigated with remaining clarified liquor. Clar. return 17 gpm minimum.	Bottom of mist eliminator washed continuously with constant 25 gpm (0.5 gpm/ft^2) diluted clarified liquor (all makeup plus necessary clarified liquor). Koch tray (2" weir ht.) irrigated with remaining clarified liquor. Clar. return 22 gpm minimum.
Scrubber Internals	3 stages (4 grids) with 5 inches spheres/stage. All beds-worn TPR spheres from previous run.	3 stages (4 grids) with 5 inches spheres/stage. All beds-worn TPR spheres from previous run.	3 stages (4 grids) with 5 inches spheres/stage. All beds-worn TPR spheres from previous run.	3 stages (4 grids) with 5 inches spheres/stage. All beds new HDPE spheres.
System Changes Before Start-of-Run	No cleaning. Mist eliminator bottom wash 20 gpm after 1/7. Minimum clarified liquor return 17 gpm after 1/10.	No cleaning. Fifth nozzle (BT 14 FCN) installed in center of existing mist eliminator underwash header.	System cleaned.	Koch tray and mist eliminator cleaned.
Method of Control	SO_2 removal controlled at 84±2%. Overrides: Inlet pH ≤ 6.0 Stoich. Ratio ≤ 1.6	SO_2 removal controlled at 87±2% Overrides: Inlet pH ≤ 6.0 Stoich. Ratio ≤ 1.6	SO_2 removal controlled at 89±2% Overrides: Inlet pH ≤ 6.0 Stoich. Ratio ≤ 1.6 Outlet SO_2 < 1000 ppm	SO_2 removal controlled at 89±2% Overrides: Inlet pH ≤ 6.1 Stoich. Ratio ≤ 1.75 Outlet SO_2 < 1000 ppm
Run Philosophy	Intended short term. To observe scrubber operation at 10 ft/sec gas velocity.	To determine if fifth nozzle on mist eliminator underwash header improves condition of mist eliminator.	To determine if higher % SO_2 removal and the fifth nozzle on mist eliminator underwash header would prevent an initially clean mist eliminator and Koch tray from plugging.	To determine the reliability and operability of the TCA system at 12.0 ft/sec gas velocity.
Results	Run terminated due to worsening condition of mist eliminator and Koch tray. Bottom of mist eliminator after 2657 hrs (Runs 535-2A, 535-2B and 536-2A) was 10% plugged with flyash (heaviest deposits in center of mist eliminator).	Run terminated due to increasing mist eliminator pressure drop. Inspection revealed mist eliminator to be 11% plugged by solids.	Run terminated when routine inspection revealed mist eliminator to be 5% plugged with solids.	Run terminated to determine factors causing unsaturated operation. Mist eliminator 11% plugged after 214 hrs. of operation. Bottom grid 60% covered with 60 mil scale.

Table 6-1 (continued)

SUMMARY OF LIMESTONE RELIABILITY TESTS ON TCA SYSTEM

Run No.	540-2A	541-2A	542-2A	543-2A
Start-of-Run Date	3/21/75	3/25/75	3/28/75	4/1/75
End-of-Run Date	3/25/75	3/28/75	4/1/75	4/3/75
On Stream Hours	90	[illegible]	91	47
Gas Rate, acfm @ 300°F	28,800	28,800	28,800	28,800
Gas Velocity, fps @ 125°F	12.0	12.0	12.0	12.0
Liquor Rate, gpm	1000	1000	1000	1000
L/G, gal/mcf	43	43	43	43
Percent Solids Recirculated	13.7-15.3	12.5-14	13.5-15.5	12.9-14.9
Effluent Residence Time, min.	15	15	15	15
Stoichiometric Ratio, moles Ca added/mole SO_2 absorbed	1.45-1.7	1.41-1.72	1.25-1.55	1.26-1.39
Avg % Limestone Utilization, 100x moles SO_2 abs./mole Ca added	63	64	74	76
Inlet SO_2 Concentration, ppm	2400-3700	2700-4000	3100-4000	2600-3500
Percent SO_2 Removal	84-94	80-88	75-85	75-84
Scrubber Inlet pH Range	5.95-6.05	5.8-5.9	5.8-5.95	5.8-5.9
Scrubber Outlet pH Range	5.75-5.9	5.5-5.7	5.35-5.6	5.3-5.4
Percent Sulfur Oxidized	10-18	16-26	10-24	10-23
Solids Disposal System	Clarifier & Filter	Clarifier & Filter	Clarifier & Filter	Clarifier & Filter
Loop Closure, % Solids, Dischg.	~40	~40	~40	~40
Calculated % Sulfate Saturation in Scrubber Inlet Liquor @ 50°C	30	45	50	135
Total Dissolved Solids, ppm	2800-3100	3100-4500	3600-4200	5000-6700
Total ΔP Range Excluding Mist Eliminator and Koch Tray, in. H_2O	6.35-6.5	6.4-6.6	6.5-7.0	6.6-6.85
Mist Eliminator and Koch Tray ΔP Range, in. H_2O	3.65-4.0	3.6-5.9	3.1-3.2	3.0-3.15
Mist Eliminator ΔP Range, in. H_2O	0.50-0.53	0.50-0.65	0.48-0.50	0.50-0.53
Absorbent	Limestone slurried to 60 wt % with clarified process liquor and added to EHT.	Limestone slurried to 60 wt % with clarified process liquor and added to EHT.	Limestone slurried to 60 wt % with clarified process liquor and added to EHT.	Limestone slurried to 60 wt % with clarified process liquor and added to EHT.
Mist Eliminator/Koch Tray	Bottom of mist eliminator washed continuously with constant 25 gpm (0.5 gpm/ft^2) diluted clarified liquor (all makeup plus necessary clarified liquor). Koch tray (2" weir ht.) irrigated with remaining clarified liquor. Clar. return 22 gpm minimum	Bottom of mist eliminator washed continuously with constant 25 gpm (0.5 gpm/ft^2) diluted clarified liquor (all makeup plus necessary clarified liquor). Koch tray (2" weir ht.) irrigated with remaining clarified liquor. Clar. return 22 gpm minimum.	Bottom of mist eliminator washed continuously with constant 25 gpm (0.5 gpm/ft^2) diluted clarified liquor (all makeup plus necessary clarified liquor). Koch tray (2" weir ht.) irrigated with remaining clarified liquor. Clar. return 22 gpm minimum.	Bottom of mist eliminator washed continuously with constant 25 gpm (0.5 gpm/ft^2) diluted clarified liquor (all makeup plus necessary clarified liquor). Koch tray (2" weir ht.) irrigated with remaining clarified liquor. Clar. return 22 gpm minimum.
Scrubber Internals	3 stages (4 grids) with 5 inches spheres/stage. All beds worn HDPE spheres from previous run.	3 stages (4 grids) with 5 inches spheres/stage. All beds worn HDPE spheres from previous run.	3 stages (4 grids) with 5 inches spheres/stage. All beds worn HDPE spheres from previous run.	3 stages (4 grids) with 5 inches spheres/stage. All beds worn HDPE spheres from previous run.
System Changes Before Start-of-Run	No changes.	No changes.	Underside of Koch tray cleaned.	No changes.
Method of Control	SO_2 removal controlled at 89±2% Overrides: Inlet pH ≯ 6.1 Stoich. Ratio ≯ 1.75 Outlet SO_2 ≯ 1000 ppm	SO_2 removal controlled at 84±2% Overrides: Inlet pH ≯ 6.0 Stoich. Ratio ≯ 1.6 Outlet SO_2 ≯ 1000 ppm	Scrubber outlet pH controlled at 5.4.	Scrubber outlet pH controlled at 5.4.
Run Philosophy	Attempt to determine effect on degree of sulfate saturation of reducing the effluent residence time from 25 min to 15 min.	Attempt to determine effect of pH on degree of sulfate saturation. SO_2 removal controlled at 84±2% to achieve inlet pH of 5.8-5.9 and outlet pH of 5.4-5.5 (similar pH levels to runs of higher L/G).	Repeat of Run 541-2A except method of control changed to outlet pH.	Attempt to determine effect on degree of sulfate saturation of raising the O_2 content of the flue gas from 5.7% to 8-9%.
Results	Run terminated as planned. Change of residence time had no significant effect on degree of sulfate saturation.	Run terminated due to rising pressure drop across Koch tray. At an average outlet pH of 5.6, degree of sulfate saturation was 45%.	Run terminated as planned. At an average outlet pH of 5.47, degree of sulfate saturation was 50%.	Run terminated as planned. Addition of air to give higher O_2 in flue gas resulted in a degree of sulfate saturation equal to 135%.

Table 6-1 (continued)

SUMMARY OF LIMESTONE RELIABILITY TESTS ON TCA SYSTEM

Run No.	564-2A	565-2A	
Start-of-Run Date	4/4/75	4/15/75	
End-of-Run Date	4/15/75	4/21/75	
On Stream Hours	269	135	
Gas Rate, acfm @ 300°F	20,500	28,800	
Gas Velocity, fps @ 125°F	8.6	12.0	
Liquor Rate, gpm	1200	1000	
L/G, gal/mcf	73	43	
Percent Solids Recirculated	12.3-15.0	13.2-14	
Effluent Residence Time, min.	15	25	
Stoichiometric Ratio, moles Ca added/mole SO_2 absorbed	1.25-1.85	1.20-1.70	
Avg % Limestone Utilization, 100x moles SO_2 abs./mole Ca added	65	69	
Inlet SO_2 Concentration, ppm	2400-3875	2400-3800	
Percent SO_2 Removal	78-90	77-89	
Scrubber Inlet pH Range	5.8-6.1	5.8-6.0	
Scrubber Outlet pH Range	5.4-5.6	5.4-5.6	
Percent Sulfur Oxidized	12-40	15-29	
Solids Disposal System	Clarifier	Clarifier & Filter	
Loop Closure, % Solids, Dischg.	35-40	~40	
Calculated % Sulfate Saturation in Scrubber Inlet Liquor @ 50°C	110	90	
Total Dissolved Solids, ppm	5000-8000	4000-8000	
Total ΔP Range Excluding Mist Eliminator and Koch Tray, in. H_2O	5.0-6.7	6.7-7.0	
Mist Eliminator and Koch Tray ΔP Range, in. H_2O	2.0-2.2	2.9-3.0	
Mist Eliminator ΔP Range, in. H_2O	0.15-0.20	0.40-0.45	
Absorbent	Limestone slurried to 60 wt % with clarified process liquor and added to EHT.	Limestone slurried to 60 wt % with clarified process liquor and added to EHT.	
Mist Eliminator/Koch Tray	Bottom of mist elim. washed cont. with 15-19 gpm dil. clar. liq. (~9 gpm makeup water + portion of clar. liq.). K.T. irrig. with remaining clar. liq. + mist elim. wash. Total clar. liq. to mist elim. & K.T. 15 gpm minimum.	Bottom of mist eliminator washed continuously with constant 25 gpm (0.5 gpm/ft^2) diluted clarified liquor (all makeup plus necessary clarified liquor). Koch tray (2" weir ht.) irrigated with remaining clarified liquor. Clar. return 22 gpm minimum.	
Scrubber Internals	3 stages (4 grids) with 5 inches spheres/stage. All beds worn HDPE spheres from previous run.	3 stages (4 grids) with 5 inches spheres/stage. All beds worn HDPE spheres from previous run.	
System Changes Before Start-of-Run	Mist eliminator cleaned in place.	No changes.	
Method of Control	SO_2 removal controlled at 84±2% Overrides: Inlet pH ≤6.3 Stoich. Ratio ≤1.6	Scrubber outlet pH controlled at 5.4±0.1.	
Run Philosophy	Run required to provide clarifier u'flow for Dravo Corp. sludge fixation tests. Conditions chosen to replicate Run 535-2A to reconfirm mist eliminator performance.	Attempt to determine whether scale formed during Run 539-2A was caused by high scrubber slurry pH (5.9-6.1 inlet, 5.6-5.8 outlet). Conditions identical to Run 539-2A except for method of control.	
Results	Run terminated after conclusion of sludge fixation testing. No new solids deposits on mist eliminator since in place cleaning at start of run.	Run terminated prematurely when inspection revealed massive failure of the HDPE spheres (~341 operating hours). No scale on bar grids.	

6.1.1 TCA Run 535-2A

Run 535-2A was begun on September 12, 1974, after the system had been cleaned. The mist elimination system consisted of a 316 stainless steel, 6-pass, closed-vane, chevron mist eliminator preceded by a Koch Flexitray used as a wash tray (see Figures 3-2 and 3-3). A detailed description of the results of the first 786 hours of operation for Run 535-2A has been presented in Reference 1. This run was continued for a total of 1835 operating hours. It was the longest limestone run made to date at the Shawnee test facility.

The major test conditions at the start of run were (Table 6-1):

Gas velocity	8.6 ft/sec
Liquid-to-gas ratio	73 gal/mcf
Percent solids recirculated	15
Effluent residence time	12 min
Percent SO_2 removal (controlled)	84

The clarified liquor return flow rate was maintained at a minimum of 15 gpm for Koch tray feed and mist eliminator wash to prevent high sulfate supersaturation in the wash tray effluent liquor. The underside of the mist eliminator was washed continuously with 15 gpm diluted clarified liquor (about 9 gpm makeup water plus about 6 gpm clarified liquor). The Koch tray was fed with the 15 gpm mist eliminator wash plus the remaining ~9 gpm (minimum) of clarified liquor. The underside of the Koch tray was sparged with 125 psig steam for 1 minute each hour.

To maintain the minimum 15 gpm clarified liquor return flow, the slurry bleed to the clarifier was allowed to fluctuate, resulting in only 12 to 13 percent solids at times in the recirculating slurry as compared to the desired 15 percent. The effluent residence time was increased from 12 to 15 minutes after 345 hours of operation to assure that sulfate saturation of the scrubber liquor would remain below 135 percent at the lower slurry solids concentration (see Figure 7-2, Reference 1).

Inspections were made after 786, 960, 1093, 1352, and 1628 hours of operation and at the end of the run after 1835 hours of operation.

After 786 hours of operation, the top of the Koch tray was clean and only 1 percent of the mist eliminator was restricted with scattered solids (mostly fly ash) on the bottom vanes. Solids had accumulated on the underside of the Koch tray and on the walls between the steam sparger and the slurry spray nozzles. The maximum deposit on one area of the walls had reached 15 inches in thickness. Approximately 30 mils of scale had accumulated on the TCA grids.* There was no measurable increase in pressure drop across the beds, Koch tray, or mist eliminator during this period of operation.

After 960 hours of operation, a two-day boiler maintenance outage forced a scrubber shutdown. The top of the Koch tray was still clean and the condition of the mist eliminator was unchanged. The underside of the Koch tray was cleaner with 60 to 70 percent of the area free of deposits. The bottom TCA grid generally had less scale. The solids accumulation on the walls between the steam sparger and the slurry spray nozzles had worsened, with the maximum deposits on one area of the walls reaching 20 inches in thickness. Four wall wash spray nozzles, using the wash tray effluent liquor, were installed to correct this situation.

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*Maximum sulfate supersaturation occurs in the scrubber effluent. Hence, scale formation is heaviest in the bottom TCA grid.

After 1093 hours of operation, the scrubber was shut down for observation of the effect of the four wall wash sprays.

Two walls were essentially clean, but, due to plugged spray nozzles, the other two walls had up to 8 inches of solids accumulation. The two plugged wall spray nozzles were cleaned before continuing the run.

A second two-day boiler maintenance outage caused the scrubber shutdown after 1352 hours of operation. The top of the Koch tray was still clean. The mist eliminator was essentially clean with only 2 to 3 percent restricted with solids. The underside of the Koch tray was slightly worse with the clean area reduced to about 50 percent. About 5 to 10 percent of the steam sparger holes were plugged with solids. Again, two wall spray nozzles were plugged, and their area of coverage had accumulated solids. The plugged nozzles were cleaned, and an in-line strainer was installed before the run was restarted. Scale accumulation on all TCA grids had decreased to less than 5 mils. The average wear of the 5-gram TPR spheres, measured during this inspection, was approximately 4 percent for 1785 hours of service.

After 1628 hours of operation, the mist eliminator and the top of the Koch tray were still essentially clean. The wall spray nozzles had remained free of plugging since the installation of the in-line strainer and all four walls below the Koch tray were essentially clean. The wall sprays were also effective in washing the underside of the Koch tray where it was covered by the sprays. The underside of the Koch tray was about 85 percent clean.

Run 535-2A was arbitrarily terminated on December 4, 1974, after 1835 operating hours, prior to the introduction of Montana low sulfur coal (see Appendix C) into boiler No. 10. At the end of the run, the top of the Koch tray was still clean and the mist eliminator was practically clean with less than 5 percent restricted by solids. The underside of the Koch tray had no solids accumulation greater than 1/4 inch thick. The walls below the Koch tray were clean to the rubber lining. The bottom TCA grid had negligible scale accumulation.

Appendix G presents average liquor compositions for the scrubber and Koch tray inlet and outlet liquors. The data given are only for the operating period after September 27, 1974, when the effluent hold tank residence time was increased from 12 to 15 minutes. The analytical data were conveniently divided into two periods having different sulfate saturations and dissolved chloride concentrations. From September 28 through October 23, 1974, the calculated average sulfate saturation was approximately 115 percent for both the scrubber inlet and outlet liquors; for the period October 24 to December 4 these saturations were about 105 percent. The lower saturation values during the second period were probably caused by the drop from 3000 to 2000 ppm in the chloride concentration (with a corresponding drop in calcium ion concentration from 1800 to 1200 ppm) in the scrubber liquor. As can be seen from Appendix G, all sulfate saturations for the scrubber and Koch tray liquors were below the critical value of 135 percent.

During the last 200 hours of Run 535-2A, the limestone makeup slurry addition point was changed from the effluent hold tank to the scrubber downcomer to observe the effect on the scrubber liquor sulfate saturation. Unlike lime wet-scrubbing in the venturi/spray tower system, the sulfate saturation in the TCA limestone system was not affected by this change in the alkali addition point.

6.1.2 TCA Run 535-2B

Run 535-2B was started on December 4, 1974 and continued until December 30, 1974, for a total of 490 operating hours. The run was a continuation of Run 535-2A during which Montana low sulfur coal was burned intermittently in boiler No. 10. The system was not cleaned prior to the test run.

Use of both high and low sulfur coals in boiler No. 10 resulted in inlet SO_2 gas concentrations ranging from 1500 to 4900 ppm. During periods of low inlet SO_2 concentration and, therefore, reduced generation of solid products, the recirculated solids concentration had to be decreased to maintain the minimum requirement of 15 gpm clarified liquor return flow to the mist elimination system. The available makeup water was decreased due to the reduced system sludge discharge.

During burning of Montana low sulfur coal, the recirculated solids concentration dropped to about 9 to 10 percent and the makeup water had to be reduced to about 5 gpm.

After 165 hours of operation (2000 hours since the system cleaning at the beginning of Run 535-2A), a five-day boiler maintenance outage from December 11 through 15 forced a scrubber shutdown. An inspection showed that a portion of the top of the wash tray had 12 to 17 mils of scale. The mist eliminator had an overall solids restriction of about 6 percent, with mist of the accumulation (up to 30 percent restricted) in the center sections. The outlet vane tips of the mist eliminator center sections directly under the outlet gas duct held 200 mils of fibrous scale and fly ash. The walls below the Koch tray had a slight gain in solids. The underside of the Koch tray was essentially unchanged. The bottom TCA grid gained new scale, resulting in about 3 percent restriction of the total free area. The scale accumulation on the walls below the bottom grid had also increased, with 1 3/4 inches of scale at the thickest spot.

Most of the Koch tray and bottom grid scaling probably occurred during the last day (December 10) of operation before the 165 hour inspection, when the inlet SO_2 concentration increased rapidly from about 1600 to 4000 ppm during a period of low makeup water and low recirculated solids concentration. The sulfate saturation exceeded 135 percent during the last 3 to 4 days before the inspection.

Several changes were made before the run was restarted on December 16 to help the system accomodate the wide swings in inlet SO_2 concentration.

To provide adequate residence time for sulfate desupersaturation during periods of low solids concentration, the residence time in the effluent hold tank was increased from 15 to 25 minutes. In addition, the clarifier underflow was returned intermittently to the effluent hold tank to maintain 15 percent recirculated solids concentration during periods of low sulfur coal. The steam sparger was removed from service to determine if the wash liquor from the four wall sprays was sufficient to keep the underside of the tray clean.*

After 330 hours of operation (2165 hours since the last system cleaning), a second inspection revealed that the amount of mist eliminator solids deposits had apparently stabilized (about 5 percent restriction), and that the top of the Koch tray was cleaner, with 5 to 10 mils of scale on 5 percent of the area. Scale on the bottom TCA grid had decreased. The underside of the Koch tray had new deposits since the steam sparger had been removed from service. Only 40 to 45 percent of the underside was free of solids. All four walls below the Koch tray were clean.

To keep the underside of the Koch tray free of solids, a single underspray nozzle, using the Koch tray effluent liquor, was installed during the outage. The four wall spray nozzles were removed from service, since the single Koch tray underspray nozzle could provide coverage and wetting of the walls below the Koch tray.

Run 535-2B was terminated as planned on December 30, 1974, after 490 hours of operation. The single Koch tray underspray nozzle had been successful in keeping all four walls below the tray clean. The underside of the Koch tray still had 60 percent of the area covered with residual scale and solids. About 60 percent of the topside of the Koch tray was covered with scale averaging 15 mils in thickness. Solids deposits in the mist eliminator had increased to an 8 to 9 percent overall restriction with the heaviest deposits again confined mostly to the center sections. The bottom TCA grid still held a light scale coating. The walls below the bottom grid had scale averaging 1/2 inch thick with a maximum of 1 3/4 inches.

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*In a full scale gas scrubbing unit, it would be undesirable to use steam to clean the underside of a wash tray.

During Run 535-2B, the calculated sulfate saturation averaged approximately 125 percent in both the scrubber inlet and outlet liquors and 120 percent in the Koch tray inlet liquor. These values are about 20 percent higher than for Run 535-2A at comparable chloride concentrations. This saturation increase probably resulted from the wide variation in inlet SO_2 concentration (1500 to 4900 ppm) which caused similarly wide variations in stoichiometry and recirculated solids concentration, both of which affect saturation.

Even though there was some scale buildup during this run, it is significant that the system was operated successfully during a period of wide variationin inlet SO_2 concentration. Since the beginning of Run 535-2A, the TCA system had operated for a total of 2325 hours without cleaning.

The average weight losses of the 5-gram TPR spheres for the top, middle, and bottom beds were 7.3, 6.2, and 3.4 percent, respectively, after a total of 2757 hours of service. Most of the spheres were dimpled.

6.1.3 TCA Run 536-2A

Run 536-2A was started on December 31, 1974 and terminated on January 15, 1975, after 328 operating hours. The objective of this test was to evaluate the operation of the TCA system at the higher gas velocity of 10 ft/sec. No cleaning of the system was done prior to startup. The mist eliminator and Koch tray had 2325 hours of operation (Runs 535-2A and 535-2B) at a gas velocity of 8.6 ft/sec.

During the run, the underside of the mist eliminator was washed continuously with 15 to 20 gpm of diluted clarified liquor (all makeup water plus necessary clarified liquor). This wash rate resulted in a specific spray rate of 0.3 to 0.4 gpm/ft^2. The Koch tray was fed with the remaining clarified liquor. The clarified liquor return to the mist elimination system was never allowed to drop below 15 gpm. This minimum flow was raised to 17 gpm on January 10 because of the higher slurry bleed rate available at the 10 ft/sec gas velocity.

The run was terminated after 328 hours when inspection revealed the mist eliminator restriction had doubled to about 16 percent. The major portion of the solids buildup was fly ash located on the middle vanes in the center of the mist eliminator. The top of the Koch tray had acquired more scale. Solids on the underside of the Koch tray had increased slightly.

The calculated saturations were 100 percent for the scrubber inlet and 105 percent for the scrubber outlet liquor. The Koch tray outlet liquor was 120 percent saturated.

6.1.4 TCA Run 537-2A

Run 537-2A was started on January 15, 1975. Operating conditions were the same as for Run 536-2A with the exceptions of an increase in TCA slurry rate to 1400 gpm (73 gal/mcf) and an increase in SO_2 removal set point to 87 percent. These changes were made to prevent the SO_2 concentration in the vicinity of the Koch tray from exceeding the level attained during the 8.6 ft/sec gas velocity tests. In addition, a fifth nozzle was installed on the mist eliminator underwash header to directly cover the center portion of the mist eliminator where plugging had occurred in the previous test. The system was not cleaned prior to startup.

The run was terminated after 137 operating hours. At that time, the system had operated for 2325 hours at 8.6 ft/sec and 465 hours at 10 ft/sec for a total of 2790 hours without cleaning. An inspection showed that the overall mist eliminator restriction had increased to 31 percent from the 16 percent at the start of the run. The scale on the Koch tray inlet and on the adjacent walls had increased slightly. About 90 tray valves were stuck in the open position where the tray was clean on the inlet side and had the greater gas flow. Thirty valves were stuck closed. The top of the tray and the wall above the tray contained more scale.

Additional scale had formed on the bottom TCA grid. Scale on one corner of the grid had bridged across four grid bars. Spheres above the grid in that corner were bound by soft, wet solids and stacked from one to six spheres high.

The calculated sulfate saturation was 125 percent for both the scrubber inlet and outlet liquors.

6.1.5 TCA Run 538-2A

Run 538-2A began on January 24, 1975 and terminated on February 21, after 562 operating hours. Test conditions for this run were the same as for Run 537-2A, except that the SO_2 removal set point was increased to 89 percent, with a maximum allowable outlet SO_2 concentration of 1000 ppm during periods of high inlet SO_2 concentrations. Prior to start of this run, the mist eliminator, Koch tray, and bottom TCA grid were cleaned. The run was made to determine if higher SO_2 removal and the fifth nozzle on the mist eliminator underwash would prevent an initially clean mist elimination system from scaling and/or plugging at the conditions tested.

A total of six inspections were made during the run. The overall restriction of the mist eliminator increased gradually to about 8 percent in about 500 hours and appeared to level out at 6 to 8 percent at the end of the run. The solids were predominately fly ash deposits at the first and second bends. The rest of the scrubber system, including the bottom TCA grid, was generally clean.

The calculated sulfate saturations were 100 percent for both the scrubber inlet and outlet liquors and 110 percent for the Koch tray outlet liquor.

The average weight losses of the 5-gram TPR spheres for the top, middle, and bottom beds were 12.4, 14.3, and 7.1 percent, respectively, in 3784 hours of service.

6.1.6 TCA Run 539-2A

Run 539-2A was designed to test the operation of the TCA system at 12.0 ft/sec gas velocity. Both the Koch tray and the mist eliminator were cleaned prior to start of this run. High-density polyethylene (HDPE) spheres were used for this run. They had been left in the beds after a series of pressure drop tests to define the regions of non-flooding TCA operation (see Section 9 for results from these tests). The run began on March 7, 1975 and terminated on March 21 after 278 hours of operation. Because of the scrubber flooding characteristics at 12 ft/sec gas velocity, the liquid-to-gas ratio was limited to 43 gal/mcf, corresponding to a slurry rate of 1000 gpm.

An inspection after 215 hours revealed the mist eliminator to be 11 percent restricted with a combination of fly ash and wet solids. The bottom TCA grid had 60 mils of scale (about 80 percent sulfite) on 60 percent of the grid bars, while the top grid had 5 mils of scale (about 80 percent sulfite) covering 50 percent of the grid bars. The top of the Koch tray was scale free. The underside had 1 to 4 mils of smooth scale plus scattered solids on 15 to 20 percent of the area. The walls below the Koch tray had 30 mils of smooth scale.

The calculated sulfate saturations for the scrubber inlet and outlet liquors were 25 and 35 percent, respectively. Because of the unexpected gypsum-unsaturated operation and the sulfite scale formation on the grids, it was decided to terminate the run and conduct a series of short-term tests to determine the factors responsible.

6.1.7 TCA Runs 540-2A through 543-2A

Run 540-2A was intended to determine the effect of reduced effluent residence time (from 25 to 15 min) on the degree of sulfate saturation of the scrubber liquor. The run was initiated on March 21 and terminated on March 25, after 90 hours of operation. The change in effluent residence time had no significant effect on the degree of sulfate saturation of the scrubber inlet liquor (20 percent versus 25 percent for Run 539-2A) under the conditions tested. This differs from the supersaturated mode of operation where sulfate saturation varies inversely with residence time (see Figure 7-2, Reference 1).

Run 541-2A was made to study the effect of lower scrubber liquor pH on the degree of sulfate saturation and on sulfite scale formation. To achieve a lower pH, the SO_2 removal set point was dropped from 89 percent to 84 percent. The run started on March 25 and terminated on March 28 after 65 operating hours, due to an increasing pressure drop across the Koch tray. The desired scrubber liquor outlet pH of 5.4 to 5.5 (as compared with 5.6 to 5.8 for Run 539-2A) was not achieved during the run. At the average outlet pH of 5.6, the sulfate saturation of the scrubber inlet liquor was 45 percent.

After cleaning the underside of the Koch tray, Run 542-2A was started on March 28 and continued until April 1 for 91 operating hours. The outlet pH was successfully controlled at 5.4 and the level of sulfate saturation of the scrubber inlet liquor was 50 percent.

Run 543-2A was intended to determine if increasing the oxygen content of the flue gas from a range of 5 to 7 percent, as in Run 539-2A, to a range of 8 to 9 percent would significantly affect the degree of sulate saturation. The scrubber outlet pH was still controlled at 5.4. The run began on April 1 and terminated on April 3 after 47 operating hours. The degree of sulfate saturation of the scrubber inlet liquor increased to an average of 135 percent during the run.

Due to time constraints, it was necessary to suspend exploratory tests to explain the sulfate-unsaturated operation and sulfite scale formation during Run 539-2A. However, a similar test effort is being continued at the EPA pilot plant facility in Research Triangle Park, North Carolina.

It was noted that limestone utilization improved from 63 to 76 percent as the scrubber liquor outlet pH was dropped from 5.8 to 5.4 during the short-term Runs 540-2A through 543-2A (see Table 6-1). As expected, SO_2 removal dropped from approximately 90 percent to 80 percent as the scrubber liquor pH decreased.

6.1.8 TCA Run 544-2A

Run 544-2A began on April 4 and terminated on April 15 after 269 operating hours. The test was intended to be short term. It was made to provide clarifier underflow sludge for fixation by Dravo Corporation and to confirm the cleanliness of the mist eliminator experienced during Run 535-2A, which lasted for 1835 hours at 8.6 ft/sec gas velocity. The run was terminated as planned after the conclusion of sludge fixation testing by Dravo.

Prior to startup, the mist eliminator had been cleaned in place. The test conditions were identical to those for Run 535-2A, except that the mist eliminator underwash rate was 15 to 19 gpm diluted clarifier liquor (as compared with a constant 15 gpm for Run 535-2A), to maintain a proper under spray pattern with the extra fifth center spray nozzle.

An inspection after 261 hours of operation (near the end of run) showed that the mist eliminator was essentially clean. The top of the Koch tray was clean, and the underside was about 90 percent clean to metal with only a small amount of thin scale remaining from the cleanup at the start of run. The walls below the Koch tray had less scale than before the start of run. The bottom TCA grid was free of scale.

The frequency of soot blowing in the flue gas inlet duct had been changed from once every four hours to once per day, beginning on March 20, 1975, near the end of Run 539-2A. The less frequent schedule appeared to be adequate in keeping the inlet duct free of accumulated solids.

The run operated at a calculated sulfate saturation of 110 percent for both the scrubber inlet and outlet liquors. These saturation values are essentially the same as for Run 535-2A.

6.1.9 TCA Run 545-2A

Run 545-2A began on April 15 and was terminated on April 21 after 133 hours of operation. The test was part of a continuing effort to determine the cause of the gypsum-unsaturated operation and sulfite scale formation experienced during TCA Run 539-2A. The system was not cleaned prior to startup. Run 545-2A was performed under conditions identical to those for Run 539-2A (e.g., 12 ft/sec gas velocity), except that the scrubber outlet pH was controlled at 5.4, compared with the average (uncontrolled) outlet pH of 5.75 for Run 539-2A. It was believed that the grid scale (about 80 percent sulfite) formed during Run 539-2A was caused by operation with high slurry pH.

The run was terminated prematurely after 133 hours when inspection revealed massive failure of the HDPE spheres, which had been in use for about 1100 operating hours. No scale was observed on any of the TCA grids.

The calculated sulfate saturation of the scrubber inlet liquor was about 90 percent, which is significantly higher than the 25 percent obtained during Run 539-2A.

6.2 MATERIAL BALANCES

The results of calcium and sulfur material balances for the TCA limestone reliability Runs 535-2A and 539-2A are summarized in Table 6-2.

The computed inlet and outlet rates for calcium and sulfur are in good agreement. This is consistant with results of earlier limestone reliability tests (see Reference 1).

Table 6-2

SUMMARY OF MATERIAL BALANCES FOR SULFUR AND CALCIUM FROM LIMESTONE RELIABILITY TESTS

Run No.	Material Balance Period, hours	Sulfur Balance			Calcium Balance			Average Stoichiometric Ratio, Moles Ca Added/Mole SO_2 Absorbed	
		SO_2 Absorbed, lb-moles/hr	SO_x in Slurry Discharged, lb-moles/hr	Percent Error	Ca in Limestone Feed, lb-moles/hr	Ca in Slurry Discharged, lb-moles/hr	Percent Error	Based on Limestone Added and SO_2 Absorbed	Based on Slurry Analysis
535-2A	472	5.8	6.1	+5	8.5	9.1	+7	1.47	1.49
539-2A	168	8.6	9.0	+5	15.2	14.4	-6	1.77	1.59

6.3 CONCLUSIONS

6.3.1 Scrubber Operation

Earlier limestone testing with the TCA had shown that scrubber internals can be kept relatively free of sulfate (gypsum) scale if the sulfate saturation of the scrubber liquor is kept below a critical value of about 135 percent (see Section 7.3, Reference 1). This can be accomplished with the proper selection of percent solids recirculated, effluent residence time, and liquid-to-gas ratio. Reliable operation below the critical sulfate saturation value was demonstrated during Run 535-2A, which continued for 1835 hours. Conditions were 12 to 15 percent solids recirculated, 15 minutes effluent residence time, and 73 gal/mcf liquid-to-gas ratio. The average sulfate saturation of both the scrubber inlet and outlet liquor was about 110 percent. During this run the bottom TCA grid, where the degree of liquor sulfate saturation is the highest, had a negligible amount of scale accumulation.

A single-nozzle underspray using Koch tray effluent liquor was used successfully to keep the underside of the Koch tray and the scrubber walls beneath the tray clean during the latter half Run 535-2A. Previously, a steam sparger and four wall wash nozzles (using Koch tray effluent liquor) had been used to prevent solids accumulations on the underside of the tray and on the walls beneath the tray, respectively.

During Run 539-2A, the scrubber recirculation liquor was unsaturated with respect to sulfate (~25 percent saturation for the scrubber inlet liquor), and sulfite scaling occurred on most scrubber surfaces below the Koch tray. The unsaturated operation was probably caused by the combination of relatively high scrubber liquor pH (~ 6.0 at the scrubber inlet and ~ 5.7 at the outlet) and relatively low liquid-to-gas ratio (43 gal/mcf*). Tests in which the scrubber liquor pH was reduced (lower stoichiometry) resulted in increased scrubber liquor sulfate saturation (Runs 541-2A, 542-2A, and 545-2A) and in the elimination of sulfite scale formation (Run 545-2A). Supersaturated liquors were obtained when the oxygen content in the flue gas was increased (from ~ 6 percent for Run 539-2A to ~ 9 percent for Run 543-2A). The causes for unsaturated operation during Run 539-2A are being further investigated at the EPA pilot facility in Research Triangle Park, North Carolina.

The 5-gram TPR spheres showed a weight loss of about 6 percent in 1757 hours of service at 8.6 ft/sec gas velocity. The weight loss was about 11.5 percent in 3784 hours of service, including 2757 hours at 8.6 ft/sec and 1027 hours at 10 ft/sec gas velocity. It is estimated that the 5-gram TPR spheres will last at least six months at 10 ft/sec gas velocity service before replacement is necessary. The TPR spheres tend to dimple, however, and can slip through the supporting bar-grids. This may be corrected by respacing the bar-grids.

The 5-gram HDPE spheres failed after about 1100 hours of service, including 800 hours at 12 ft/sec and 300 hours at 8.6 ft/sec gas velocity.

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*The liquid-to-gas ratio was limited to 43 gal/mcf because of scrubber flooding at the 12 ft/sec gas velocity (see Section 9).

There has been no evidence of significant erosion of the 316 stainless steel bar-grids in the TCA after over 9000 hours of operation.

The four 316 stainless steel slurry spray nozzles, Spraco No. 1969F, showed no significant erosion after over 4500 hours of service with 15 percent slurry at 5 psi pressure drop.

6.3.2 Wash Tray/Mist Eliminator Operation

The most significant reliability problem encountered during the TCA limestone reliability tests has been associated with scaling and/or plugging of the Koch Flexitray and bottom vanes of the stainless steel, 6-pass, closed-vane chevron mist eliminator. Earlier limestone reliability test results have shown that the mist eliminator and top surface of the Koch tray can be kept relatively free of scale if the irrigation liquor is low in sulfate saturation (see Reference 1).

Run 535-2A demonstrated long-term reliability of this mist elimination system at 8.6 ft/sec scrubber gas velocity (5.6 ft/sec superficial gas velocity in the Koch tray and mist eliminator areas) and 15 percent solids recirculated. The top surface of the Koch tray was entirely clean and the mist eliminator was practically clean (less than 5 percent restricted by solids) after 1835 hours of operation before intermittent burning of Montana low sulfur coal in boiler No. 10 caused operational upsets (see Run 535-2B).

At scrubber gas velocities of 10 ft/sec or higher, plugging of the chevron mist eliminator by solids (mostly fly ash) became a problem. At 10 ft/sec scrubber gas velocity (6.5 ft/sec in the mist eliminator and Koch tray areas), the overall restriction of the mist eliminator increased gradually to about 8 percent during the first 500 hours of operation and appeared to level out at 6 to 8 percent after 562 operating hours (Run 538-2A). At 12 ft/sec scrubber gas velocity (7.8 ft/sec in the mist eliminator and Koch tray areas), the mist eliminator was 11 percent plugged by solids within only 215 hours of operation (Run 539-2A).

Section 7

OPERATING EXPERIENCE DURING LIME/LIMESTONE TESTING

This section summarizes the operating experience during lime/limestone testing at the Shawnee facility from October 1974 through April 1975. A summary of prior operating experience is presented in Reference 1.

7.1 MIST ELIMINATION SYSTEMS

7.1.1 Venturi/Spray Tower System

A 3-pass, open-vane, 316 stainless steel, horizontal chevron mist eliminator (see Figure 3-3) with intermittent high pressure underside washing and sequential low pressure topside washing has operated reliably at 8 percent slurry solids concentration and at spray tower gas velocities up to 8.0 ft/sec (Runs 623-1A and 624-1A). The underside was washed for ~ 4 minutes every 4 hours with ~ 3 gpm/ft^2 makeup water at 45 psig nozzle pressure. The topside was washed with makeup water on an 8-hour sequential cycle with 1 of the 6 nozzles activated for 4 minutes every 80 minutes. Spray rate was 0.5 gpm/ft^2 at 13 psig nozzle pressure. This mist eliminator system will be tested at higher gas velocities after the 5-week boiler outage in May 1975.

A cone-shaped, 4-pass, closed-vane, 316 stainless steel, chevron mist eliminator (see Figure 3-3) was unsuccessfully tested for a short period (Runs 611-1A, 618-1A, 619-1A, and 621-1A). As it appeared improbable that such a design would be applicable to a full scale unit, testing of this mist eliminator was terminated.

7.1.2 TCA System

The TCA mist elimination system consisted of a 6-pass, closed-vane, 316 stainless steel, horizontal chevron mist eliminator (see Figure 3-3) preceded by a Koch Flexitray used as a wash tray. The underside of the mist eliminator was continuously washed with a 60/40 mixture of makeup water and charified liquor at 15 gpm (0.3 gpm/ft^2). The Koch tray was fed with the mist eliminator wash plus 9 gpm of clarified liquor. The underside of the Koch tray was continuously washed with the Koch tray effluent liquor.

Reliability was demonstrated for this system during 1835 hours of operation (Run 535-2A) at 8.6 ft/sec scrubber gas velocity and 15 percent slurry solids concentration. At the end of this run, the Koch tray was clean and the mist eliminator was essentially clean with less than 5 percent restriction by soft solids.

At scrubber gas velocities of 10 ft/sec and greater (Runs 536-2A through 539-2A), buildup of deposits (mostly fly ash) on the mist eliminator have been a significant problem. Other mist elimination systems will be tested on the TCA at scrubber gas velocities up to 12.5 ft/sec after the 5-week boiler outage in May 1975 (see Figure 4-1).

7.2 SCRUBBER INTERNALS

7.2.1 TCA Grid Supports

The 3/8 inch diameter, stainless steel bar-grids, installed on 1 1/4 inch centers in October 1973, have been in slurry service for over 9000 hours with no evidence of significant erosion.

7.2.2 TCA Plastic Spheres

Earlier testing indicated that 5-gram thermoplastic rubber (TPR) spheres should have a service life of up to one year at 8.6 ft/sec scrubber gas velocity. This observation has been further substantiated by recent data which showed a 6 percent weight loss after 2757 hours of operation at 8.6 ft/sec for a new batch of 5-gram TPR spheres. However, after an additional 1027 hours (3784 hours total) at a 10 ft/sec scrubber gas velocity, the weight loss had increased to 11.5 percent. At the higher gas rate therefore, the service life would approach only 6 months. The 5-gram TPR spheres tend to dimple and can slip through the supporting grid bars. This may be corrected by respacing the bar-grids.

High-density polyethylene (HDPE) spheres lasted only 1100 hours before a massive failure occurred. The 1100 hours of service included 800 hours at 12 ft/sec and 300 hours at 8.6 ft/sec gas velocity.

After the May 1975 boiler outage, the wear rate on new 6-gram TPR spheres will be tested. The 6-gram TPR spheres should be more dimple-resistant.

7.2.3 Spray Tower Nozzles

Bete No. ST48FCN stellite tipped nozzles were used in the spray tower. They have operated at 10 psi pressure drop with slurry containing 8 percent suspended solids. The stellite tips have shown negligible wear after 7200 hours of slurry service, but some erosion (15 percent weight loss) in the 316 stainless steel bases has been observed.

7.2.4 TCA Nozzles

The four TCA slurry feed nozzles were installed in September 1974. These were Spraco No. 1969F, full cone, open type nozzles, made of 316 stainless steel. No significant wear has been observed after 4500 hours of operation at a 5 psi pressure drop with slurry containing 15 percent suspended solids.

7.2.5 Venturi Internals

The venturi scrubber at Shawnee is a variable throat, 316 stainless steel venturi manufactured by Chemico Corp. During the current operating period both stress cracking and erosion have been noted at several interior parts.

Inspection after shut down for the May 1975 boiler outage revealed stress cracking on the portion of the inlet duct that extends into the venturi; a 4-inch wide, half circle of duct had fallen off. Also, an 8-inch hairline crack was discovered in the venturi housing at the point where the bull nozzle enters the venturi. The stress cracking did not appear serious and was repaired by welding.

Severe erosion, however, has been noted on the plug shaft protection shroud and guide vanes. The erosion has been severe enough to require steps to prevent damage to the plug shaft. The most successful repair method has been to cover the affected areas with an expendable material that can be replaced periodically. The best material used to date has been neoprene which has lasted slightly over 2000 hours.

7.3 HOT-GAS/LIQUID INTERFACE

The hot (300 to 330°F) flue gas feed must be cooled before entering the neoprene rubber-lined TCA to a temperature below 190°F, the maximum permissible for liner protection. Cooling of the feed gas is not required at the venturi scrubber inlet during normal operation since the venturi scrubber itself is an efficient humidifying device.

The TCA flue gas cooling system, developed in early 1973 (see Reference 1), consists of 3 spray nozzles installed at the top and side walls within the flue gas inlet duct. The nozzles are fed with recirculating slurry. A sootblower is provided to periodically blow off the accumulated slurry solids into the scrubber downcomer. The system has been successful in eliminating solids buildup in the inlet duct.

The sootblowing frequency was successfully reduced in March 1975 from once every 4 hours to once a day. No increase in the inlet duct solids buildup has been experienced.

7.4 REHEATERS

Flue gas from the scrubber is reheated to prevent condensation and corrosion in the exhaust system, to facilitate isokinetic and analytical sampling, to protect the induced draft fans from solid deposits and droplet erosion, and to increase plume buoyancy.

The reheater on the TCA (supplied by Hauck Manufacturing Co.) is a fuel-oil-fired unit with separate combustion air supply and with combustion occurring in the flue gas stream. This unit has been extensively modified (see Reference 1) to facilitate operation, but burner flameout has continued to be a problem.

An identical unit on the venturi/spray tower system was modified in March 1974 to incorporate a fuel-oil-fired external combustion chamber (manufactured by Bloom Engineering Co.). This unit has operated reliably with minimum flameout and equipment problems for over 7000 hours.

Inspection of the reheater on the venturi/spray tower system during the May 1975 five-week boiler outage revealed some cracking of the refractory in the combustion chamber discharge section throat. Repairs were made by using a mixture of 15 percent Kaocrete and 85 percent Kruzite castable #32 refractory (A.P. Green Co., Mexico, Missouri).

The reheater on the TCA will be modified during the May 1975 boiler outage to include a Bloom external combustion chamber.

7.5 FANS

The 316 stainless steel fans at the Shawnee test facility are induced draft, centrifugal fans manufactured by Zurn Industries. Reliability has been good during the current operating period, with no system downtime due to fan problems. Previously some vibrational problems were encountered, but these have been solved by changing pillow blocks and greasing the fan bearings on a weekly basis (see Reference 1).

During the May 1975 boiler outage, a four-inch hairline crack was discovered in the fan rotor shroud of the venturi/spray tower fan. The crack was repaired by welding with a type 347 stainless steel rod.

7.6 PUMPS

Pump problems during the current operating period (see Reference 1 for a report on prior operation) have been due mainly to pump seal failures. In February 1973, when most of the rubber-lined centrifugal pumps (manufactured by Allen-Sherman-Hoff) were converted from Hydroseal (water flushed packing) to Centriseal (air flushed packing), several shaft failures were experienced on A-frame (50 to 100 gpm capacity) pumps. Hardened stainless steel shaft sleeves were installed and shaft failures have been eliminated.

Frequent packing failure on the Centriseal pumps has continued to be a problem on A-frame pumps since adequate purge air cannot be maintained without vapor locking the pump. A T1 Crane XD-101 (316) single seal, double hardface mechanical seal will be installed on an A-frame pump during the May 1975 boiler outage for evaluation when the system is restarted.

Packing failure has not been as frequent with larger pumps since the seal purge air volume is small compared with the pump volume and an adequate air flow can be maintained.

The alkali addition system pumps are positive displacement pumps manufactured by Moyno Pump Division of Robbins & Myer Co. They were installed in November 1972 when the limestone system was converted to provide a 60 wt % limestone slurry. The pumps are oversized by a factor of two. They are allowed to wear until the required flow can no longer be maintained. Typical operating life for a rotor is 2000 hours and for a stator, 1000 hours.

7.7 WASTE SOLIDS HANDLING

7.7.1 Filter

Due to frequent cloth failure and cake discharge difficulties, the Maxibelt rotary drum vacuum filter was coverted to a single roll type with air blowback and scraper discharge in February 1975.

The filter cloth life has been somewhat extended but a longer period of normal filter operation will be required to determine realistic cloth life. The first cloth installed after the filter modification lasted over 600 hours, but subsequent cloths have had much shorter lives due to secondary causes (e.g., cloth deterioration during extended shutdowns or broken tension ropes resulting in the cloth catching and tearing on the discharge scraper).

7.7.2 Centrifuge

The centrifuge was reactivated when a solids dewatering capacity greater than that of the clarifier alone was needed because of higher flue gas flow rates on the TCA. The repaired centrifuge (see Reference 1 for a description) has operated satisfactorily during 1745 hours of intermittent operation.

Inspection during the May 1975 boiler outage revealed evidence of significant wear but no maintenance was performed.

7.7.3 Clarifiers

Overloading of the TCA clarifier has occurred at times during operation at 12 ft/sec gas velocity. In an attempt to maintain clear overflow, the feedwell on the TCA clarifier will be extended during the May 1975 boiler outage to provide more liquid up-flow residence time and to minimize short-circuiting.

7.8 ALKALI ADDITION SYSTEMS

7.8.1 Lime

The lime addition system consists of a storage silo, lime slaker (manufactured by Portec-Cahaba), a slaked lime holding tank, and associated feed pumps. An analysis of the lime used can be found in Appendix C. Fresh water is used to slake the lime to approximately 20 to 25 weight percent.

The system has given excellent reliability in over 9000 hours of intermittent operation. Maintenance requirements have been minimal. A discussion of the pump operation can be found in Section 7.6.

7.8.2 Limestone

The limestone addition system consists of a drying-grinding system, a storage tank, belt feeder, slurry tank, and associated feed pumps. An analysis of the ground limestone can be found in Appendix C. Clarified process liquor is used to slurry the limestone to 60 weight percent.

The drying-grinding system was acquired from an earlier EPA sponsored dry limestone injection program at the Shawnee Power Station. It has given satisfactory performance with minimum maintenance during the three years of the alkali wet-scrubber test program.

The slurry system was modified to provide 60 wt % limestone slurry in November 1972 and was further modified to incorporate clarified process liquor for slurrying the limestone in March 1974. Since March 1974 the system has operated satisfactorily in almost 7000 hours of intermittent operation with minimal maintenance. A discussion of pump operation can be found in Section 7.6.

7.9 INSTRUMENT OPERATING EXPERIENCE

7.9.1 pH Meters

The main problem (see Reference 1) associated with the Uniloc Model 321 submersible pH meters has been scale formation on the probes and subsequent measurement error. The scale is removed by rinsing with HCl.

On April, 1975, a continuous ultrasonic cleaner (a Uniloc add-on) was installed on the venturi/spray tower inlet pH meter to aid in the prevention of scale buildup. Although the device has operated for less than a month, due to the unit No. 10 boiler outage, it appears to have significantly reduced scale buildup. Before the installation, scale was removed daily. With the ultrasonic cleaner, once every five days has been sufficient. All probes are routinely rinsed with water about twice a week.

7.9.2 Flowmeters

Operation with the Foxboro magnetic flow meters in slurry service has generally been satisfactory, but some difficulties have been experienced with deterioration of the liners in the 1 1/2 inch meters. These meters were originally lined with Scothane. After failure they were relined with Adiprene-L. The new liners have failed after periods ranging from 3 to 9 months due to blister formation, subsequent erosion of the blister, and eventual stripping away of the liner.

Larger meters (6 to 8 inch size) are lined with neoprene and smaller meters (1/2 inch size) are lined with Teflon. No difficulties with liner deterioration have been experienced with these meters. It is planned to reline the 1 1/2 inch meters with Teflon.

7.10 LINING MATERIALS

Lining or coating materials for equipment at the Shawnee facility generally consist of neoprene rubber (pipes, pumps, scrubber internal walls, and small tanks) or Flakeline 103 (effluent hold tanks and clarifiers). Flakeline 103 is a bisphenol-A type of polyester resin filled 25 to 35 percent with glass flake. It is manufactured by Ceilcote Company.

Both rubber and Flakeline coatings have shown very little erosion or deterioration. Successful repairs have been made using Epoxylite-203, an epoxy marine coating consisting of Polypoxy 4216A plus Polypoxy 4027B produced by Tettit Co., Rockway Beach, New Jersey. A patch on the venturi/spray tower effluent hold tank agitator blade has shown little wear after over 9000 hours.

Section 8

PARTICULATE REMOVAL TEST RESULTS

Presented in Tables 8-1 and 8-2 are overall particulate removal efficiencies measured during reliability testing on the venturi/spray tower and TCA systems, respectively. For these tests, a modified EPA particulate train (manufactured by Aerotherm/Acurex Corporation) was used to measure mass loading at the scrubber inlets and outlets.

For the venturi/spray tower system (see Table 8-1), particulate removals of 99.0 to 99.3 percent were obtained for spray tower gas velocities of 6.7 to 8.0 ft/sec, venturi pressure drops of 1.9 to 9.0 inches H_2O, and liquid-to-gas ratios of 5 to 30 gal/mcf and 50 to 60 gal/mcf for the venturi and spray tower, respectively.

For the TCA system (see Table 8-2), the removals were 99.0 to 99.7 percent for gas velocities of 8.6 to 12.5 ft/sec, total pressure drops of 6.1 to 10.0 inches H_2O, and liquid-to-gas ratios of 42 to 104 gal/mcf.

Results of particulate removal tests prior to reliability testing are reported in Section 11 of Reference 1. The current results are in good agreement with the earlier test results.

Table 8-1

OVERALL PARTICULATE REMOVAL IN VENTURI/SPRAY TOWER DURING LIME RELIABILITY TESTS

Run No.	Date	Gas Rate, acfm @ 330°F	Spray Tower Gas Velocity, ft/sec @ 125°F	Liquor Rate, gpm		L/G, gal/mcf		Pressure Drop, in. H_2O		Grain Loading, grains/scf		Percent Removal
				Venturi	Spray Tower	Venturi	Spray Tower	Venturi	Spray Tower[(a)]	Inlet	Outlet	
604-1A	6/26/74	25,000	6.7	100	1200	5	60	1.9	3.0	2.52	0.024	99.1
608-1A	9/11/74	↓	↓	600	↓	30	↓	9.0	2.2	2.28	0.023	99.0
610-1A	10/9/74	↓	↓	↓	↓	↓	↓	↓	3.2	2.72	0.021	99.2
611-1A	11/6/74	↓	↓	↓	↓	↓	↓	↓	3.0	2.36	0.021	99.1
622-1A	2/18/75	↓	↓	↓	↓	↓	↓	↓	3.0	3.02	0.022	99.3
624-1A	3/26/75	30,000	8.0	↓	↓			↓	4.5	1.58	0.015	99.0
624-1A	3/28/75	↓	↓	↓	↓	25	50	↓	4.5	2.47	0.022	99.1
624-1A	4/4/75	↓	↓	↓	↓	↓	↓	↓	4.3	2.14	0.018	99.2

(a) Including mist eliminator

Table 8-2

OVERALL PARTICULATE REMOVAL IN T .A SCRUBBER DURING LIMESTONE RELIABILITY TESTS

Run No.	Date	Gas Rate, acfm @ 300°F	Gas Velocity, ft/sec @ 125°F	Liquor Rate, gpm	L/G, gal/mcf	Pressure Drop,[a] in. H_2O	Grain Loading, grains/scf		Percent Removal
							Inlet	Outlet	
531-2A	5/15/74	20,500	8.6	1200	73	6.7	2.82	0.029	99.0
531-2A	6/12/74	↓	↓	1200	73	10.0[b]	3.47	0.010	99.7
532-2A	7/24/74			1700	104	6.7	3.33	0.024	99.3
535-2A	9/27/74			1200	73	6.2	2.73	0.016	99.4
535-2A	10/30/74			1200	73	6.2	2.24	0.023	99.0
535-2A	11/20/74			1200	73	6.1	2.97	0.021	99.3
536-2A	1/9/75	24,000	10.0	1200	62	8.0	2.88	0.012	99.6
538-2A	2/13/75	24,000	10.0	1400	73	8.7	2.18	0.018	99.2
539-2A	3/6/75	29,900	12.5	1000	42	10.0	3.00	0.017	99.4
539-2A	3/11/75	28,800	12.0	1000	43	10.0	2.82	0.014	99.5

(a) Including mist eliminator and Koch tray.

(b) High pressure drop due to system plugging by scale and solids.

A limited number of particulate tests on the TCA system to determine removal as a function of particle size are also reported in Section 11 of Reference 1. Future testing by EPA is planned to confirm the validity of these results.

Section 9

ANALYSIS OF TCA PRESSURE DROP DATA

This section presents a pressure drop correlation fitted to data on the TCA system. A series of tests were made in late February and early March 1975 to obtain pressure drop data for the four-grid, three-bed TCA configuration. These data were needed to define the range of non-flooding operation as a function of gas and liquor flow rate and sphere bed height. An earlier correlation had been developed for the TCA system with wire mesh grids (see Reference 1) which have since been replaced with bar-grids.

Figures 9-1 through 9-4 present the measured TCA pressure drop data as a function of gas and liquor flow rate with 0, 5, and 7 1/2 inches of spheres per bed. Flooding was indicated by a rapid increase in pressure drop. This occurred at approximately 8 to 10 inches H_2O. Both high-density polyethylene (HDPE) and thermoplastic rubber (TPR) spheres were used in these tests. As can be seen in Figures 9-2 and 9-3, pressure drop does not seem to depend on which type of sphere is used.

The following equation was fitted to the data shown in Figure 9-1 for the four-grid TCA without spheres:

$$\Delta P = 0.221\, v + 0.0355(L/A) - 1.89 \qquad (9\text{-}1)$$

where:

ΔP = pressure drop across four grids, inches H_2O

v = saturated gas velocity at 125°F based on tower cross-sectional area, ft/sec

L/A = liquor flow rate per unit tower cross-sectional area ($A = 32\ ft^2$), gpm/ft^2

Equation 9-1 accounts for 98.9 percent of the variation of the data with a standard error of estimate of 0.075 inch H_2O.* The range of variables covered by this equation included:

Gas velocity (v): 8 to 13.5 ft/sec

Liquor flow rate per unit cross-section (L/A): 25 to 45 gpm/ft^2

Number of grids: 4

No spheres

The following equation was fitted to the data shown in Figures 9-2 through 9-4 for the four-grid TCA with spheres, for pressure drops below 10 inches H_2O.

$$\Delta P = 1.68 + 7.17 \cdot 10^{-5}\, h_s\, (L/A)\, v^2 \qquad (9\text{-}2)$$

where:

ΔP = pressure drop across the four-grids and three beds (5 to 7 1/2 inches of spheres per bed), inches H_2O.

h_s = total static height of spheres in inches.

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*See Appendix H for definition of statistical terms.

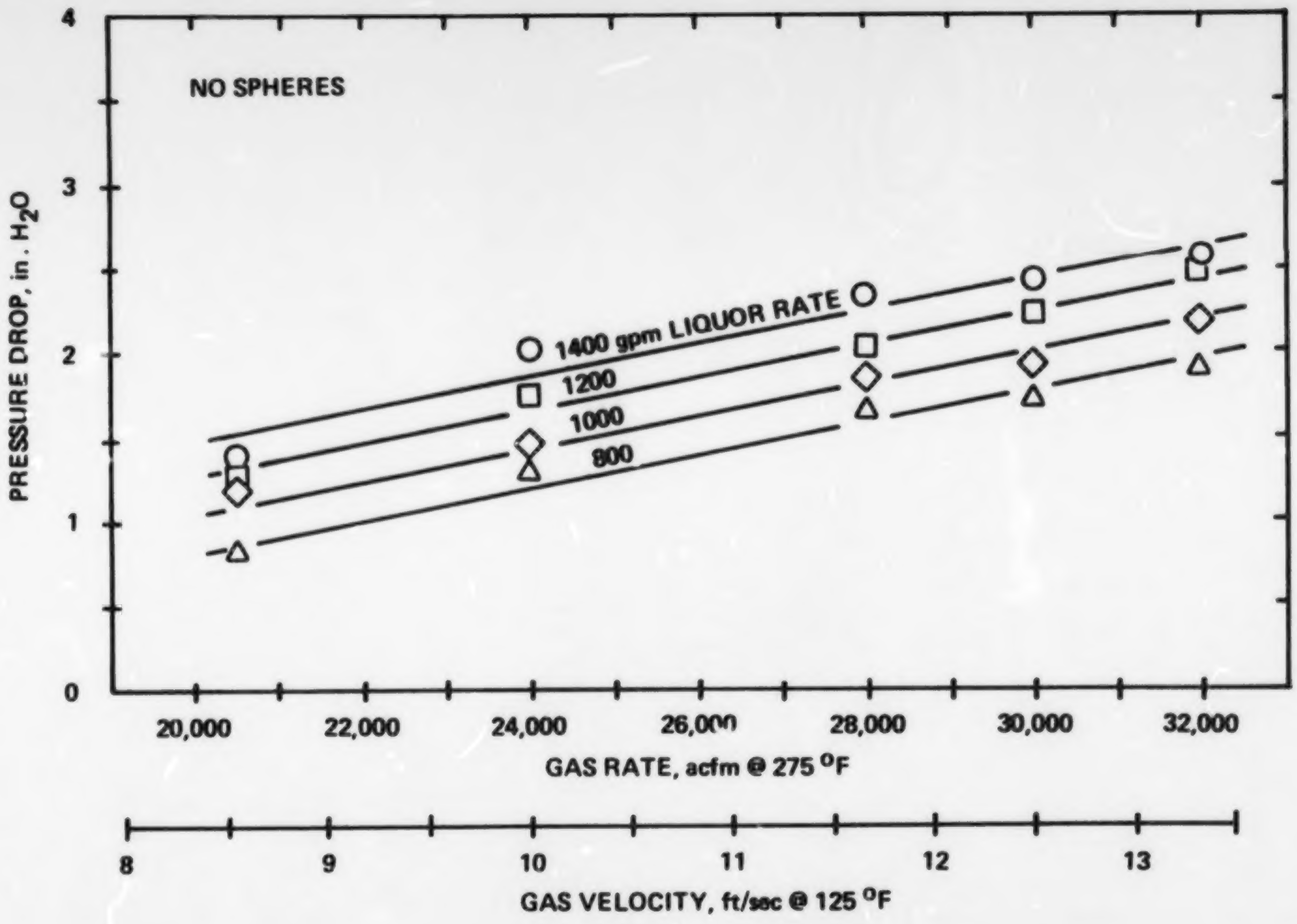


Figure 9-1. Pressure Drop Across the Four-Grid TCA Without Spheres

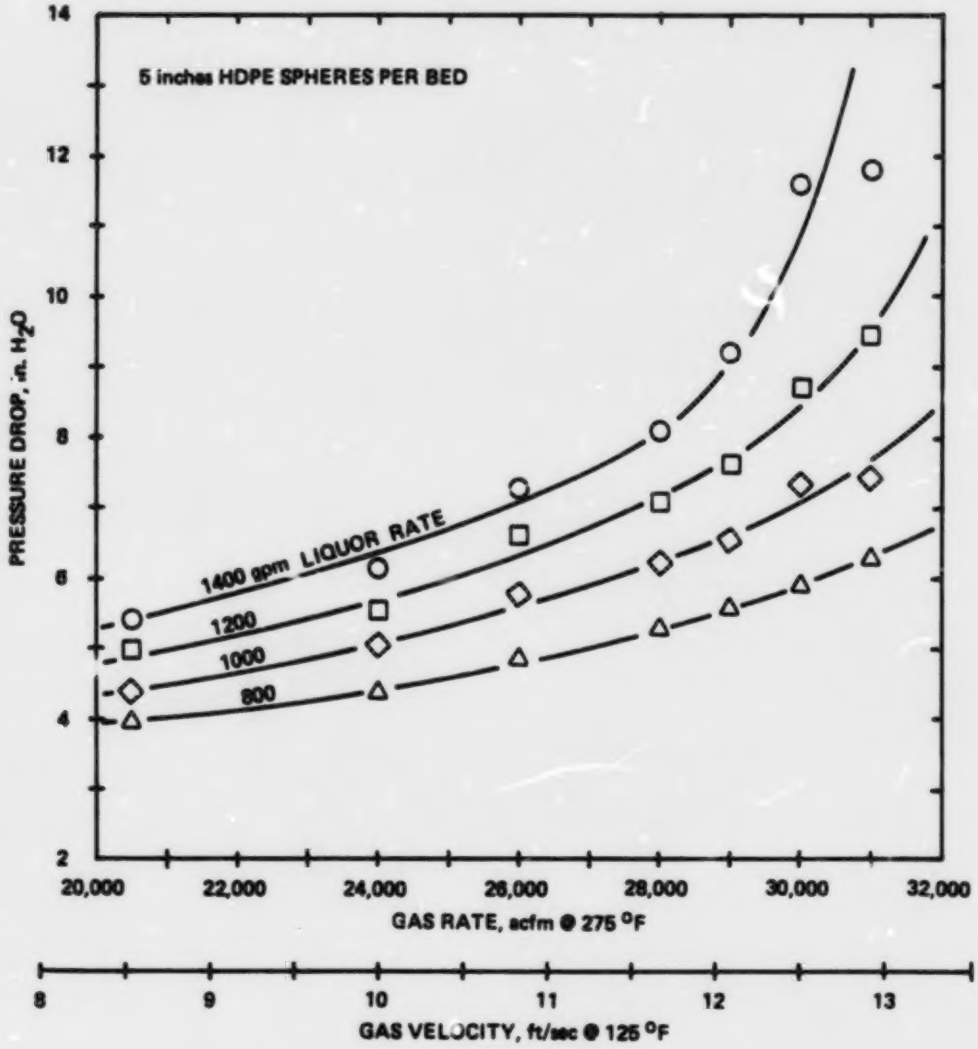


Figure 9-2. Pressure Drop Across the Four-Grid, Three-Bed TCA with Five Inches of HDPE Spheres per Bed

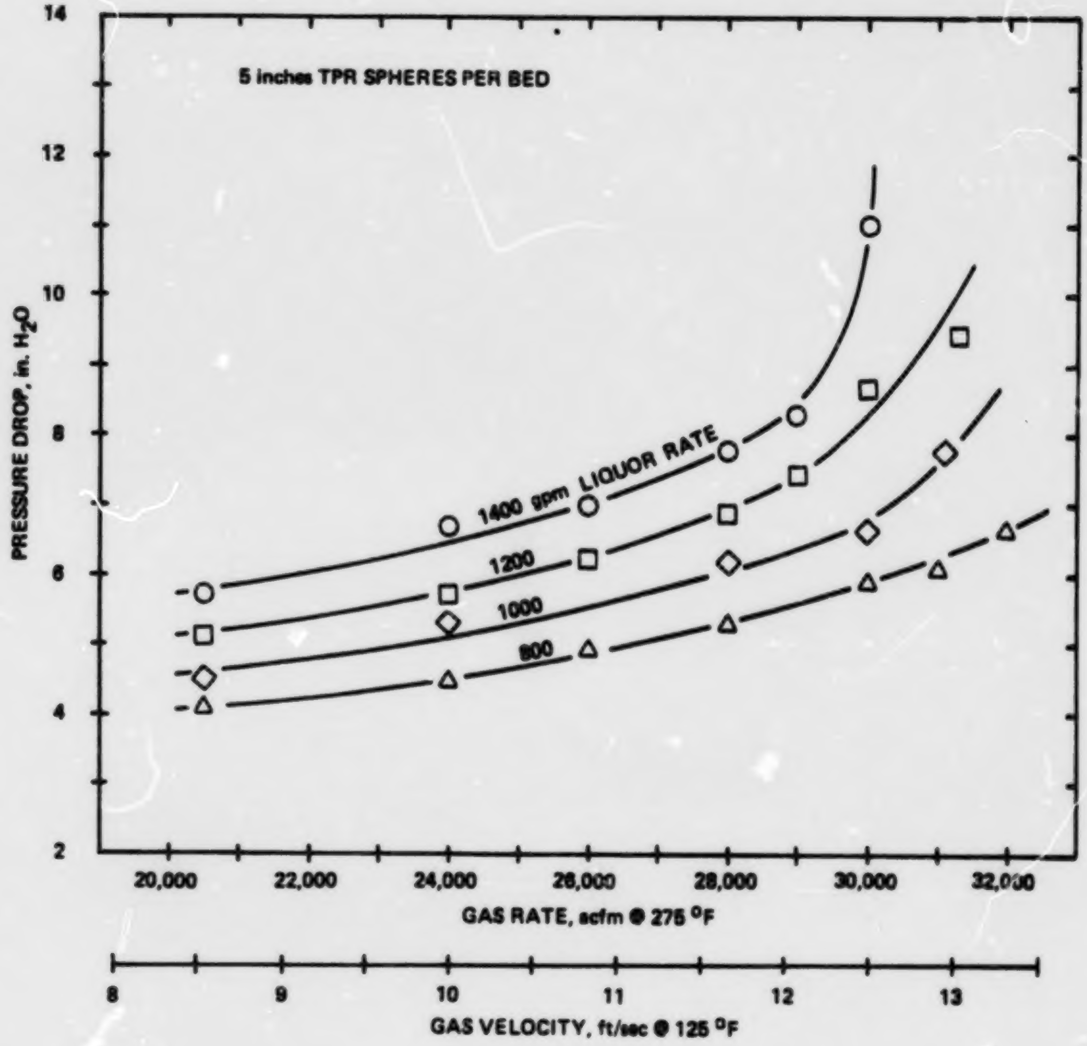


Figure 9-3. Pressure Drop Across the Four-Grid, Three-Bed TCA with Five Inches of TPR Spheres Per Bed

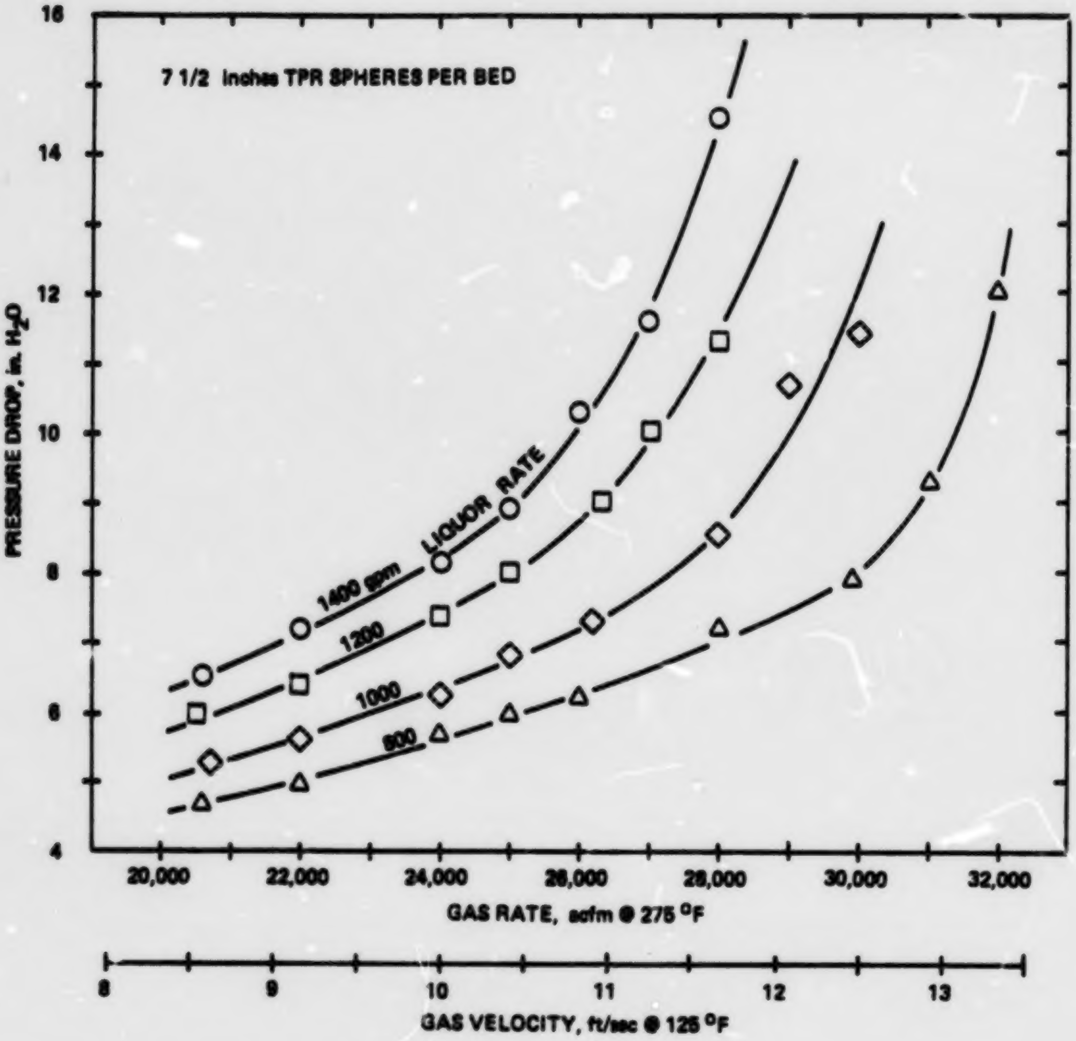


Figure 9-4. Pressure Drop Across the Four-Grid, Three-Bed TCA with Seven and One-Half Inches of TPR Spheres per Bed

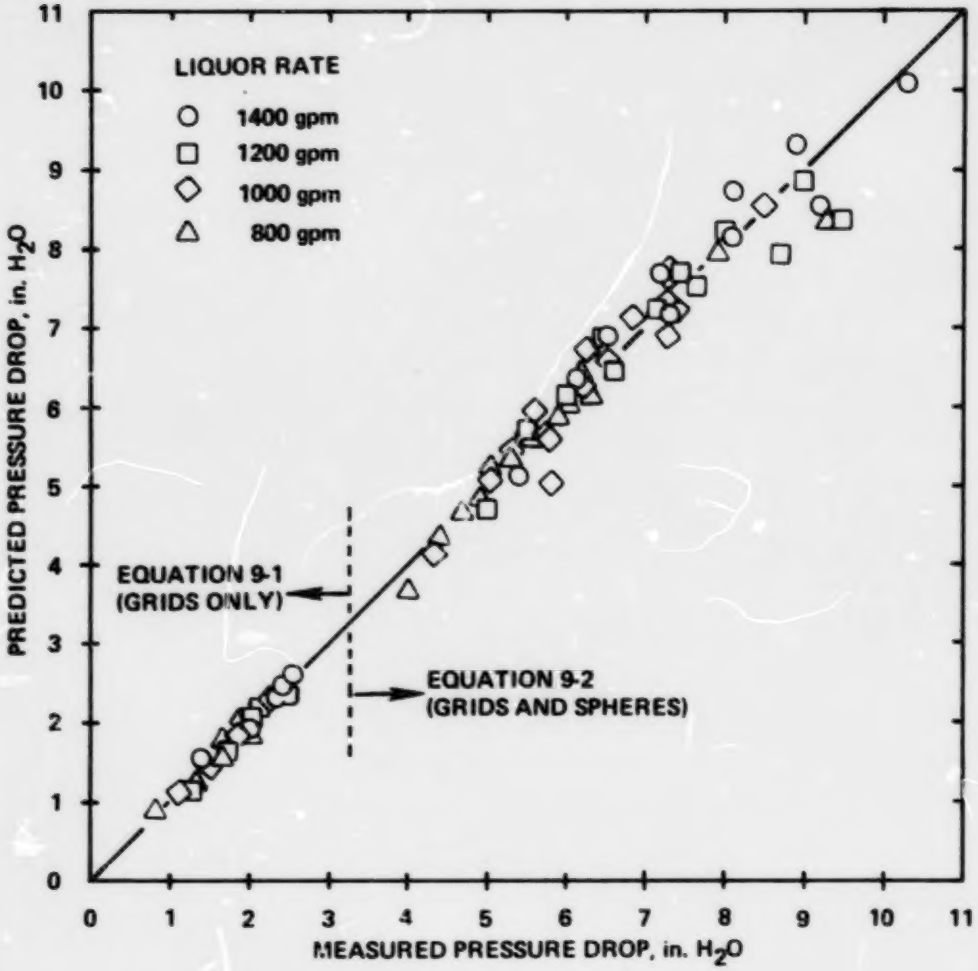


Figure 9-5. Comparison of Experimental Data and Predicted Values of Pressure Drop for the Four-Grid, Three-Bed TCA

Equation 9-2 accounts for 97.3 percent of the variation of the data with a standard error of estimate of 0.35 inch H_2O. The range of variables covered by this equation included:

Pressure drop (ΔP) $\geqq$ 10 inches H_2O (non-flooding region only)

Gas velocity (v): 8.5 to 13.5 ft/sec

Liquor flow rate per unit cross-section (L/A): 25 to 45 gpm

Total height of spheres (h_s): 15 to 22.5 inches

Type of spheres: HDPE or TPR hollow spheres, 1 1/2 inch diameter, 5 gram average weight

Number of grids: 4

Number of beds: 3

The measured and predicted values of pressure drop from Equations 9-1 and 9-2 are compared in Figure 9-5.

Section 10

REFERENCES

1. Bechtel Corporation, EPA Alkali Scrubbing Test Facility: Summary of Testing through October 1974, EPA Report 650/2-75-047, June 1975.

2. Universal Oil Products, Air Correction Division, Bulletin No. 608, "UOP Wet Scrubbers," 1971.

3. R. H. Borgwardt, "EPA/RTP Studies Related to Unsaturated Operation of Lime and Limestone Scrubbers," Proceedings: Symposium on Flue Gas Desulfurization - Atlanta, November 1974, EPA Report 650/2-74-126, December 1974.

4. R. H. Borgwardt, "Increasing Limestone Utilization in FGD Scrubbers," to be presented at the Sixty-Eighth Annual Meeting of the AIChE, Los Angeles, November 16-20, 1975.

Appendix A

CONVERTING UNITS OF MEASURE

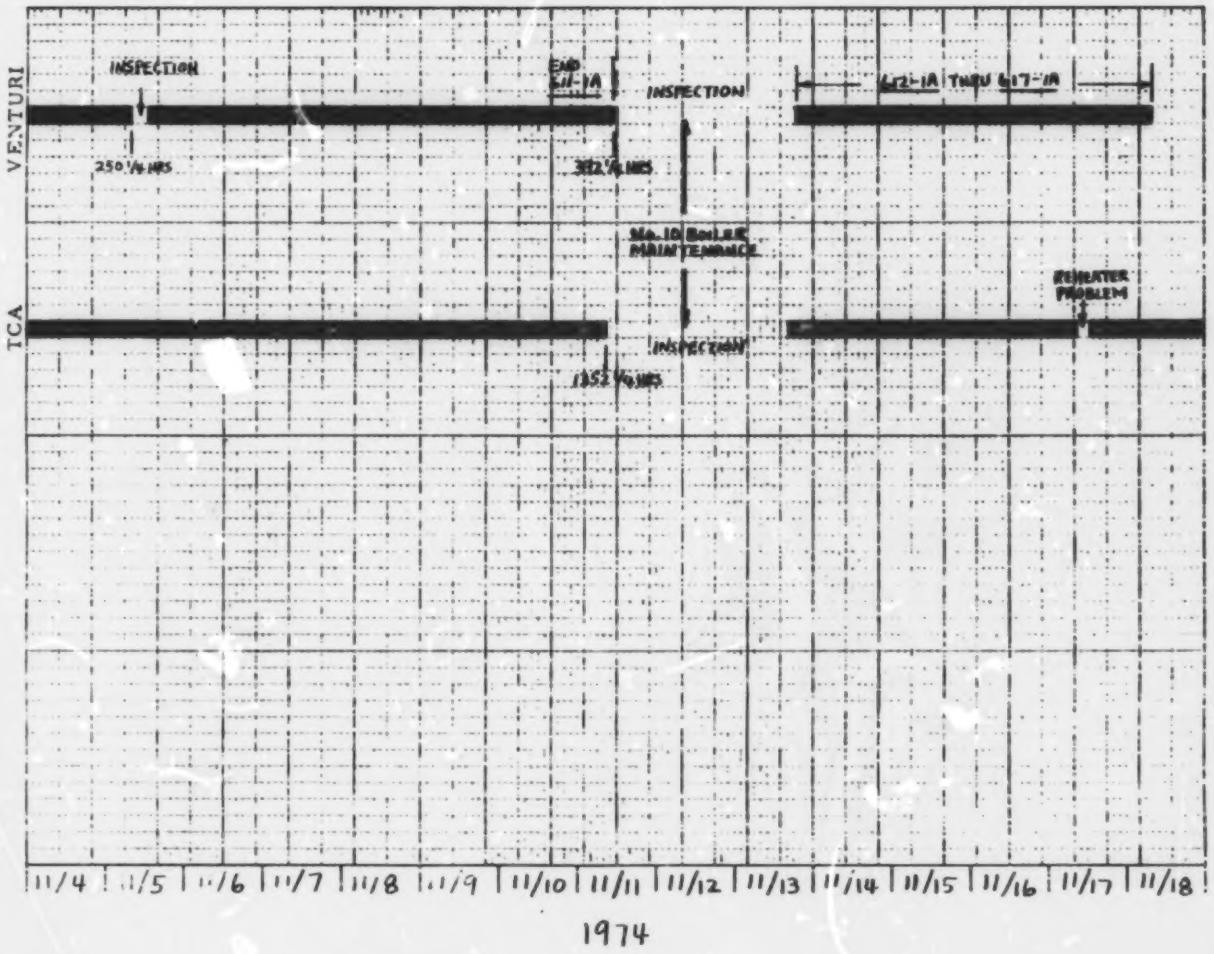
Environmental Protection Agency policy is to express all measurements in Agency documents in metric units. When implementing this practice will result in undue costs or lack of clarity, conversion factors are provided for the non-metric units used in the report. Generally, this report uses British units of measure. For conversion to the metric system, use the following conversions:

To Convert From	To	Multiply By
scfm (60°F)	nm^3/hr (0°C)	1.61
cfm	m^3/hr	1.70
°F	°C	subtract 32 then ÷ 1.8
ft	m	0.305
ft/hr	m/hr	0.305
ft/sec	m/sec	0.305
ft^2	m^2	0.0929
ft^2/tons per day	m^2/metric tons per day	0.102
gal/mcf	ℓ/m^3	0.134
gpm	ℓ/min	3.79
gpm/ft^2	ℓ/min/m^2	40.8
gr/scf	gm/m^3	2.29
in.	cm	2.54
in. H_2O	mm Hg	1.87
lb	gm	454
lb-moles	gm-moles	454
lb-moles/hr	gm-moles/min	7.56
lb-moles/hr ft^2	gm-moles/min/m^2	81.4
lb-moles/min	gm-moles/sec	7.56

Appendix B

SCRUBBER OPERATING PERIODS

SCRUBBER OPERATING PERIODS



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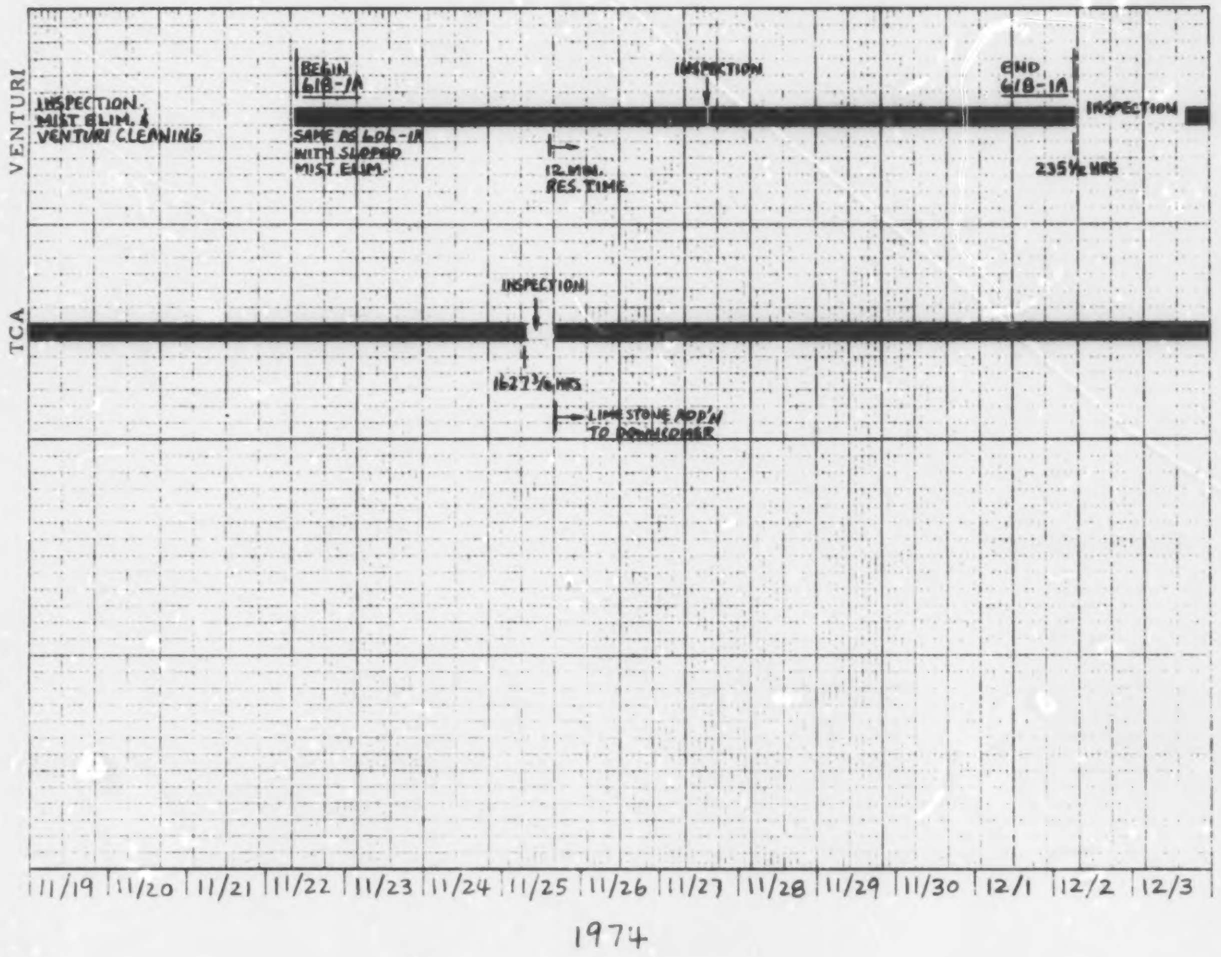

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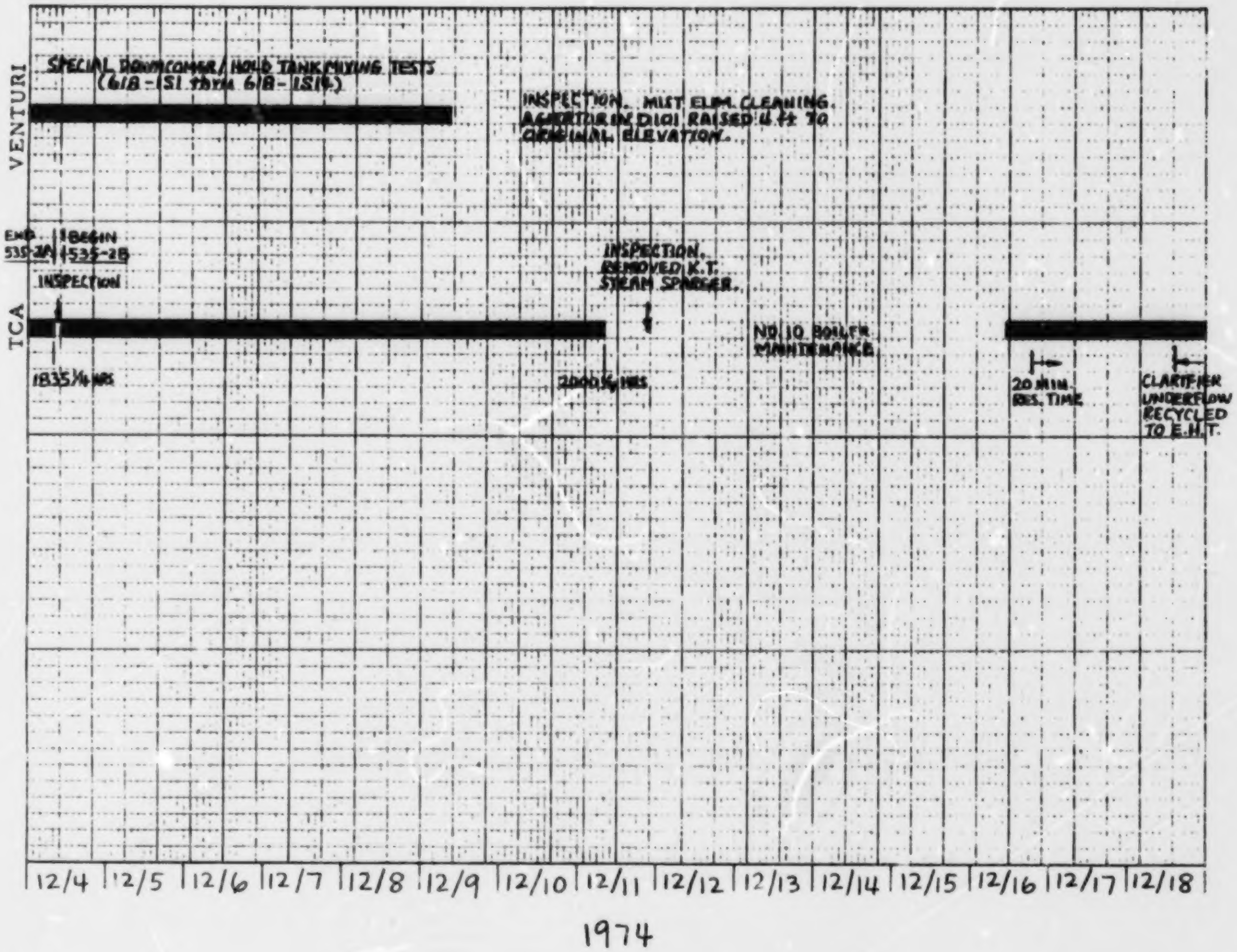

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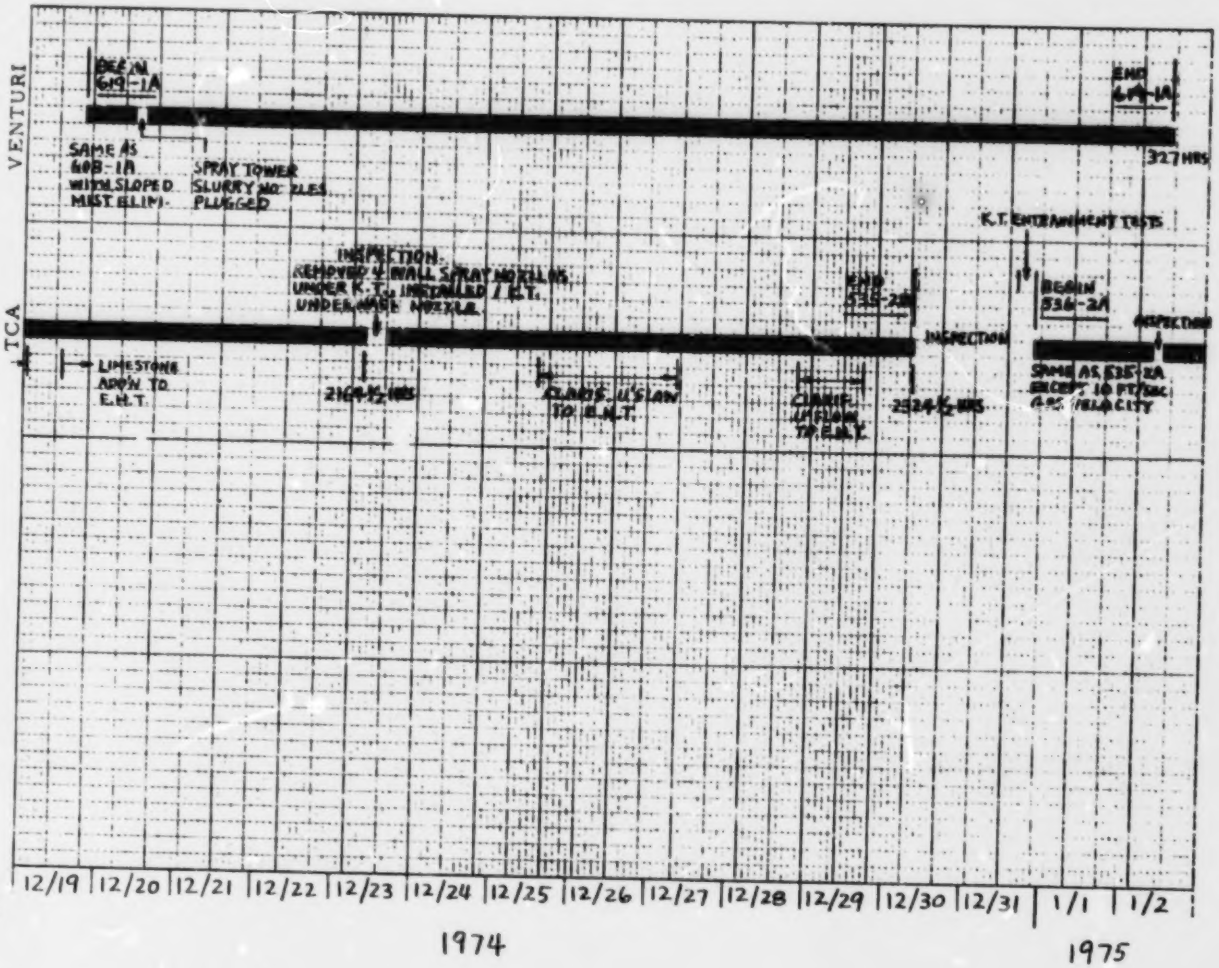

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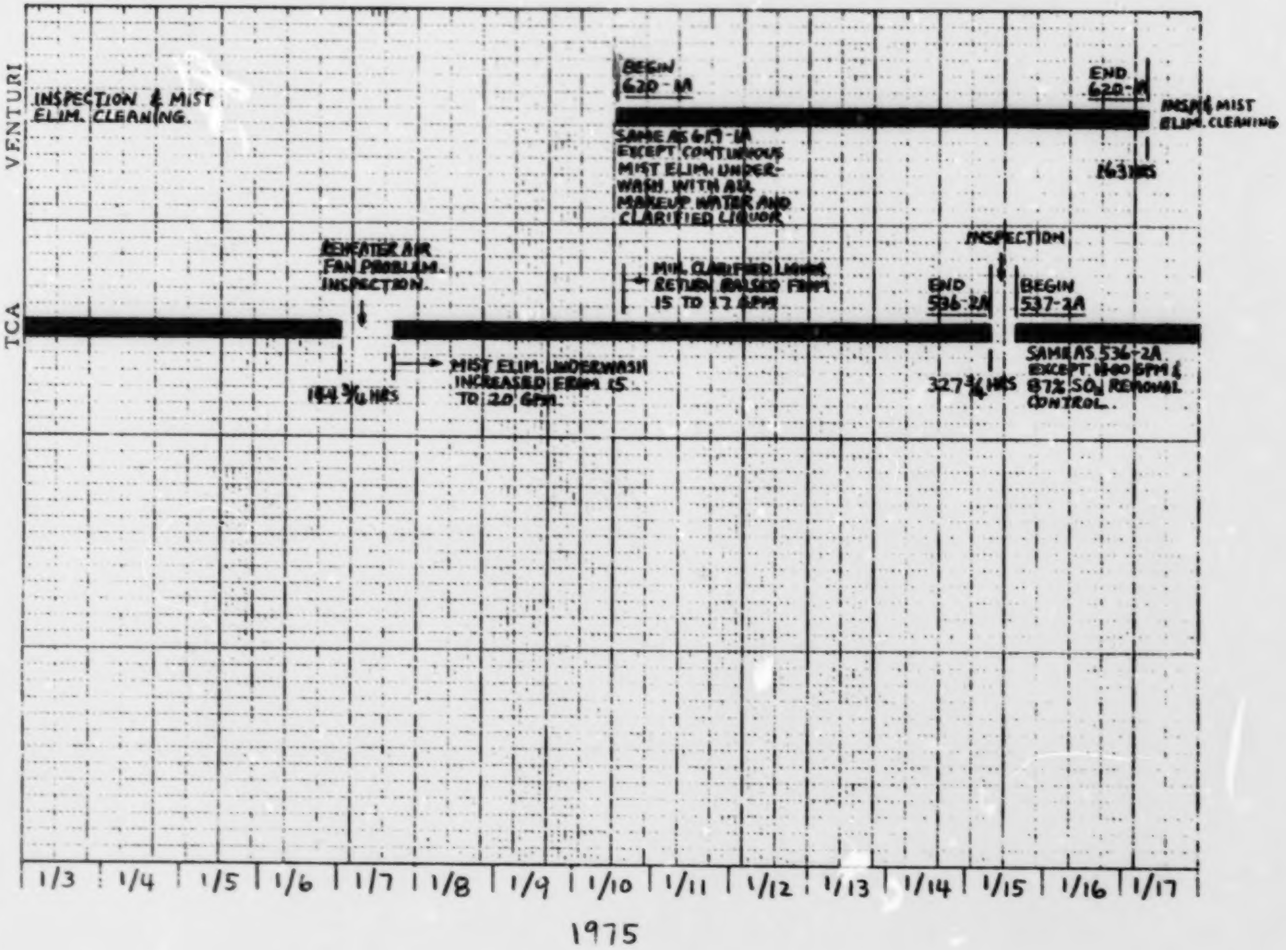

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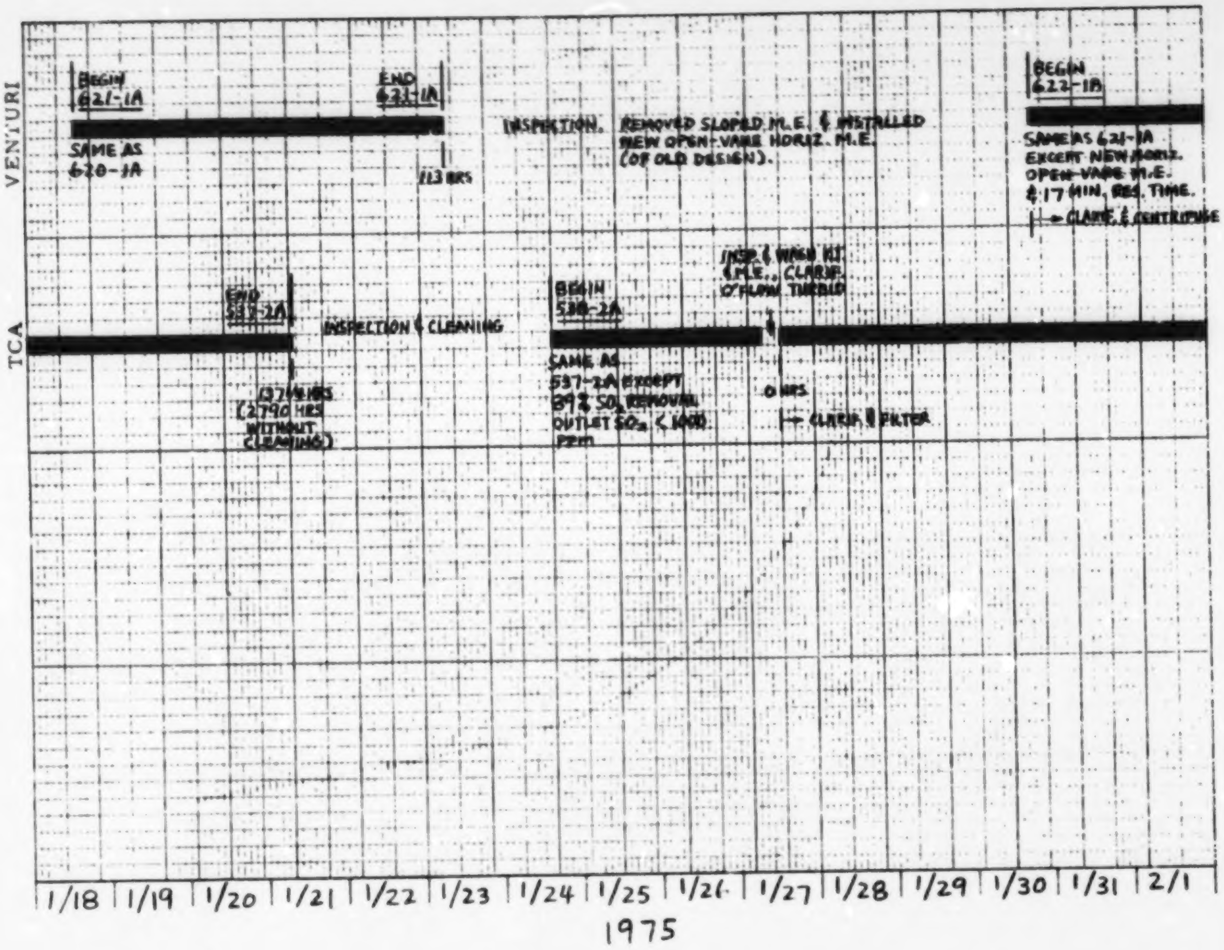

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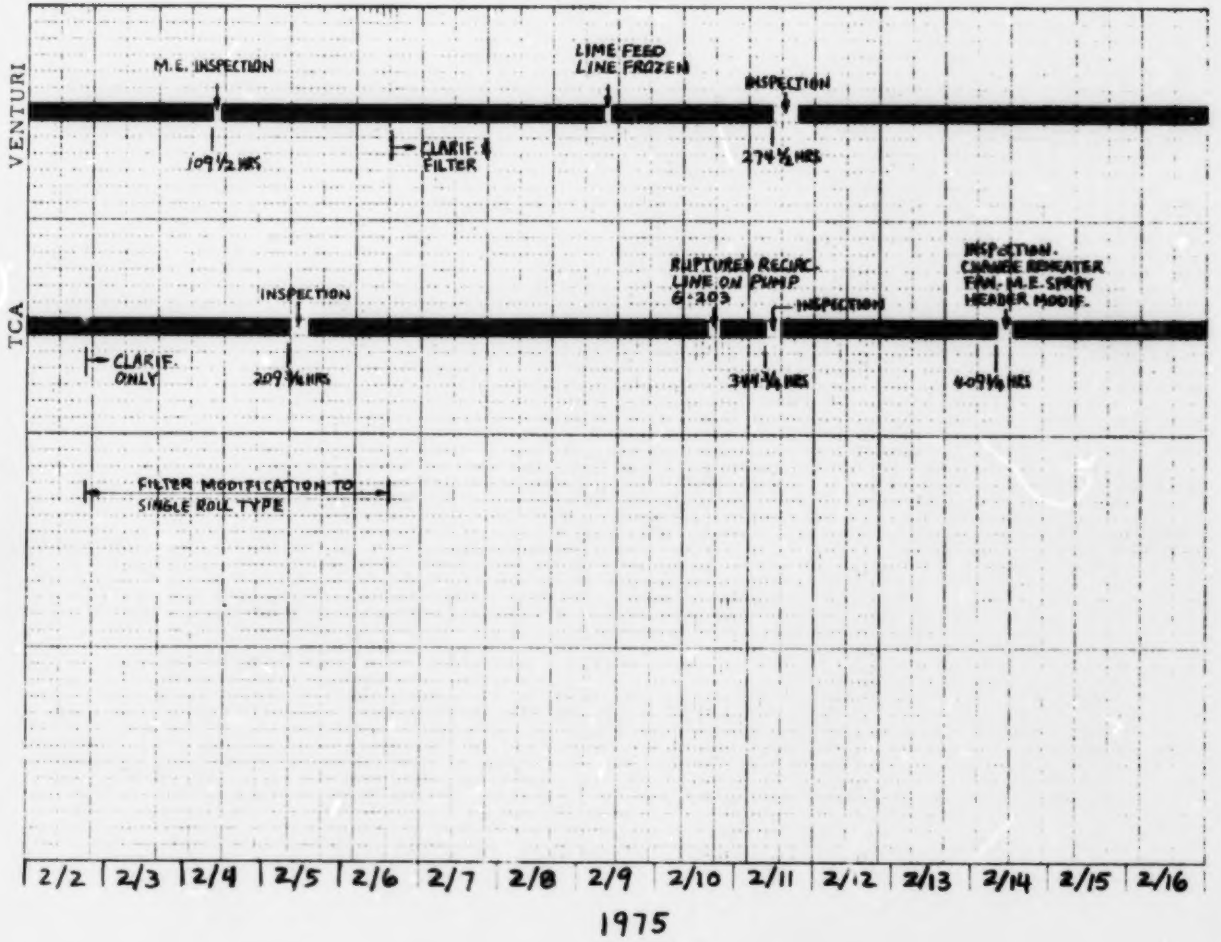

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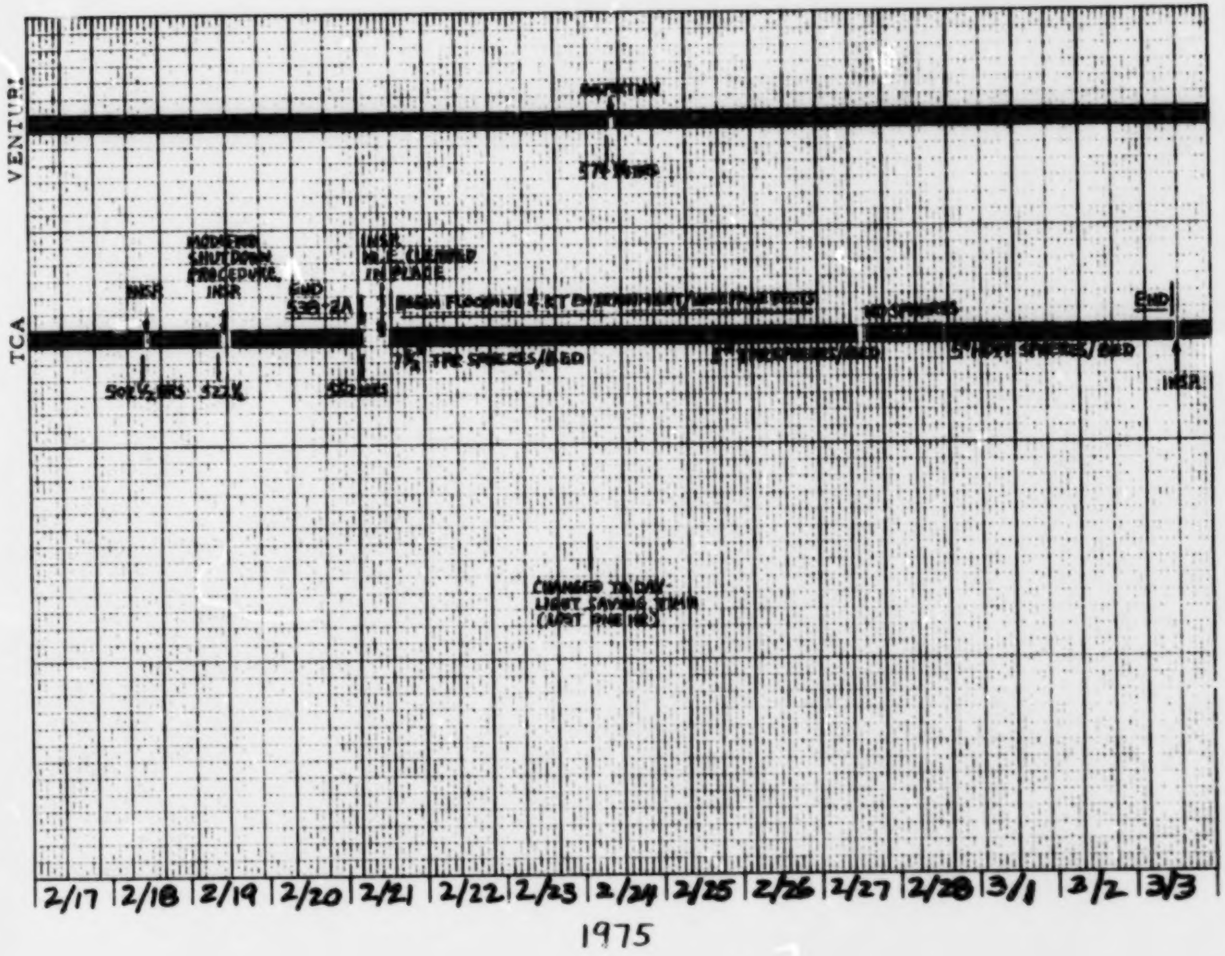

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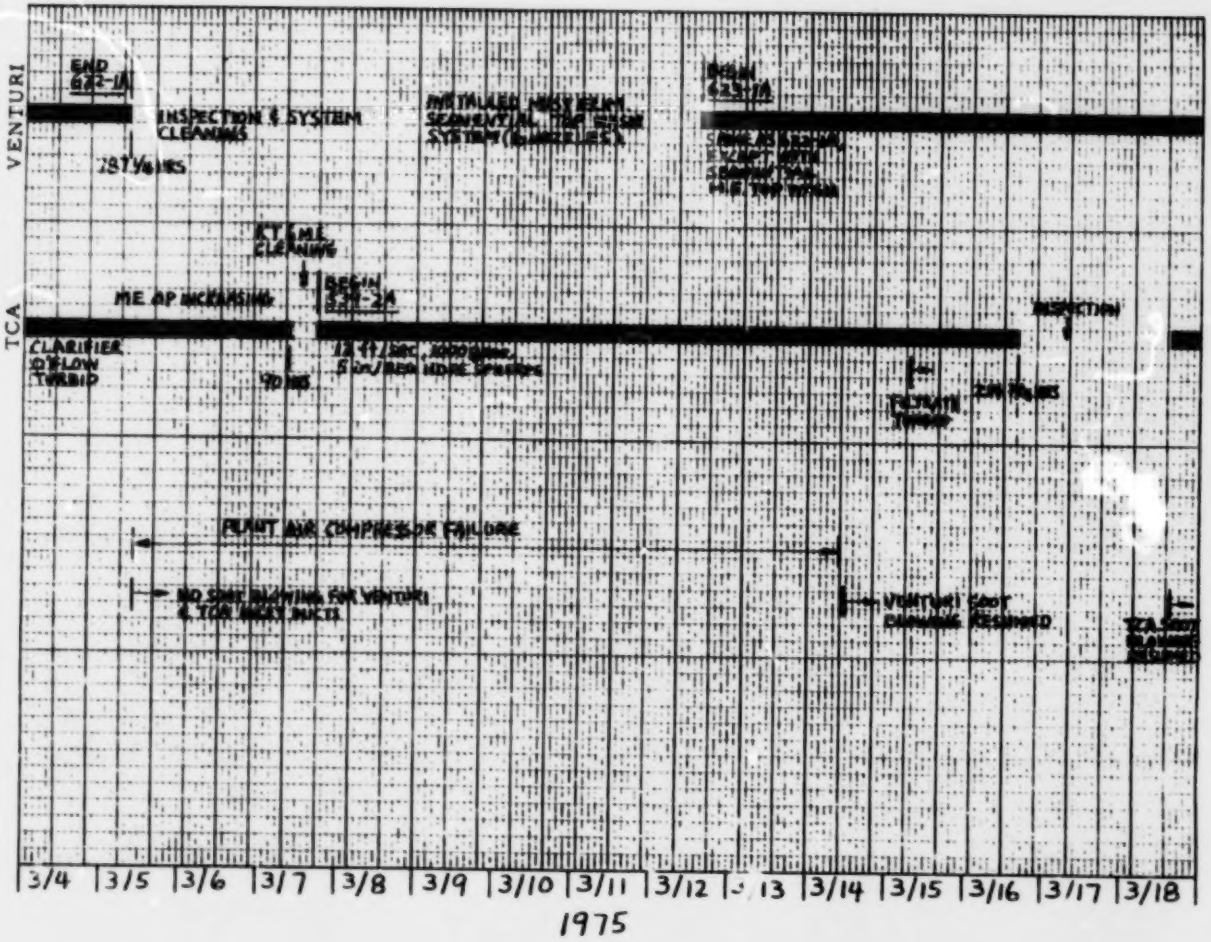

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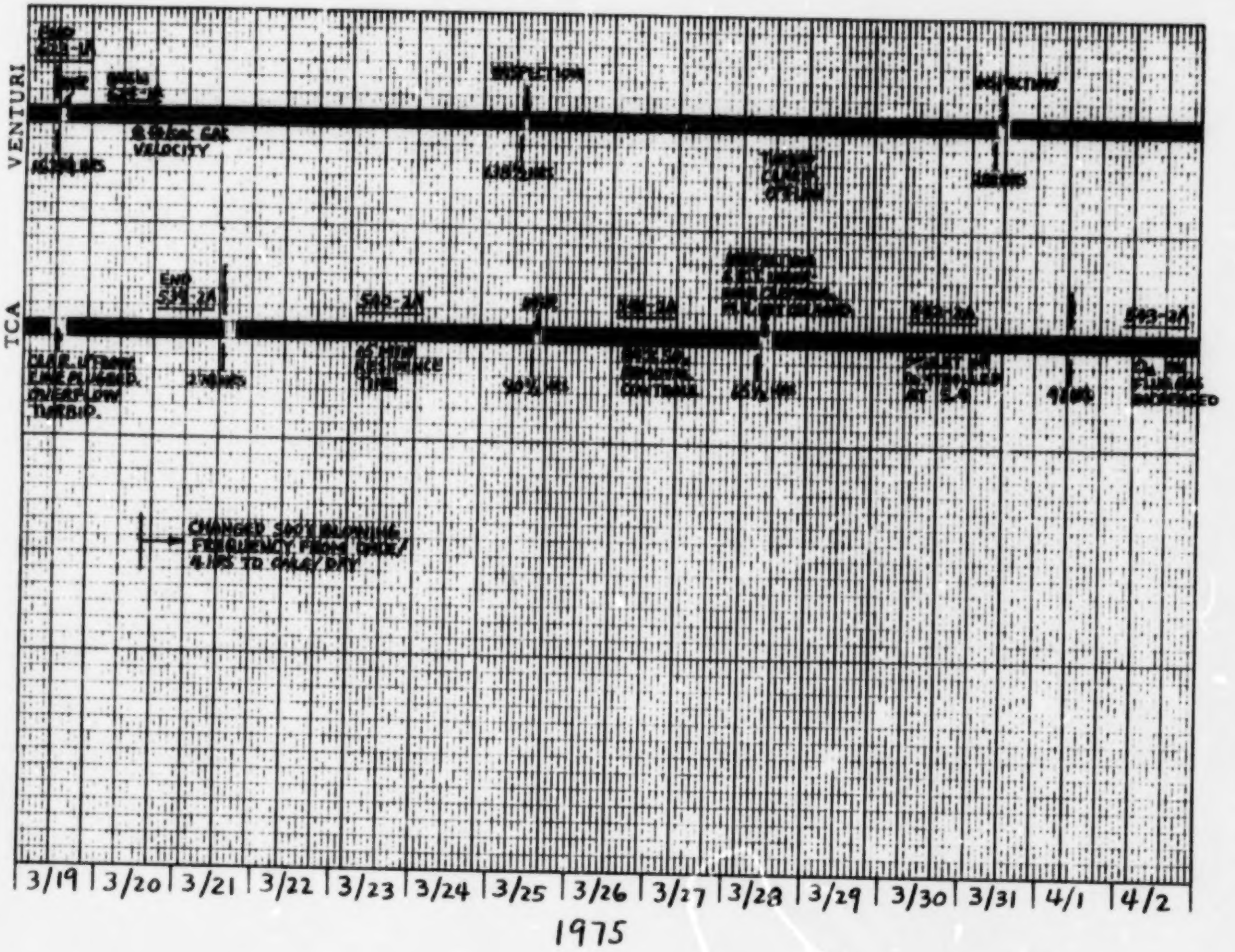

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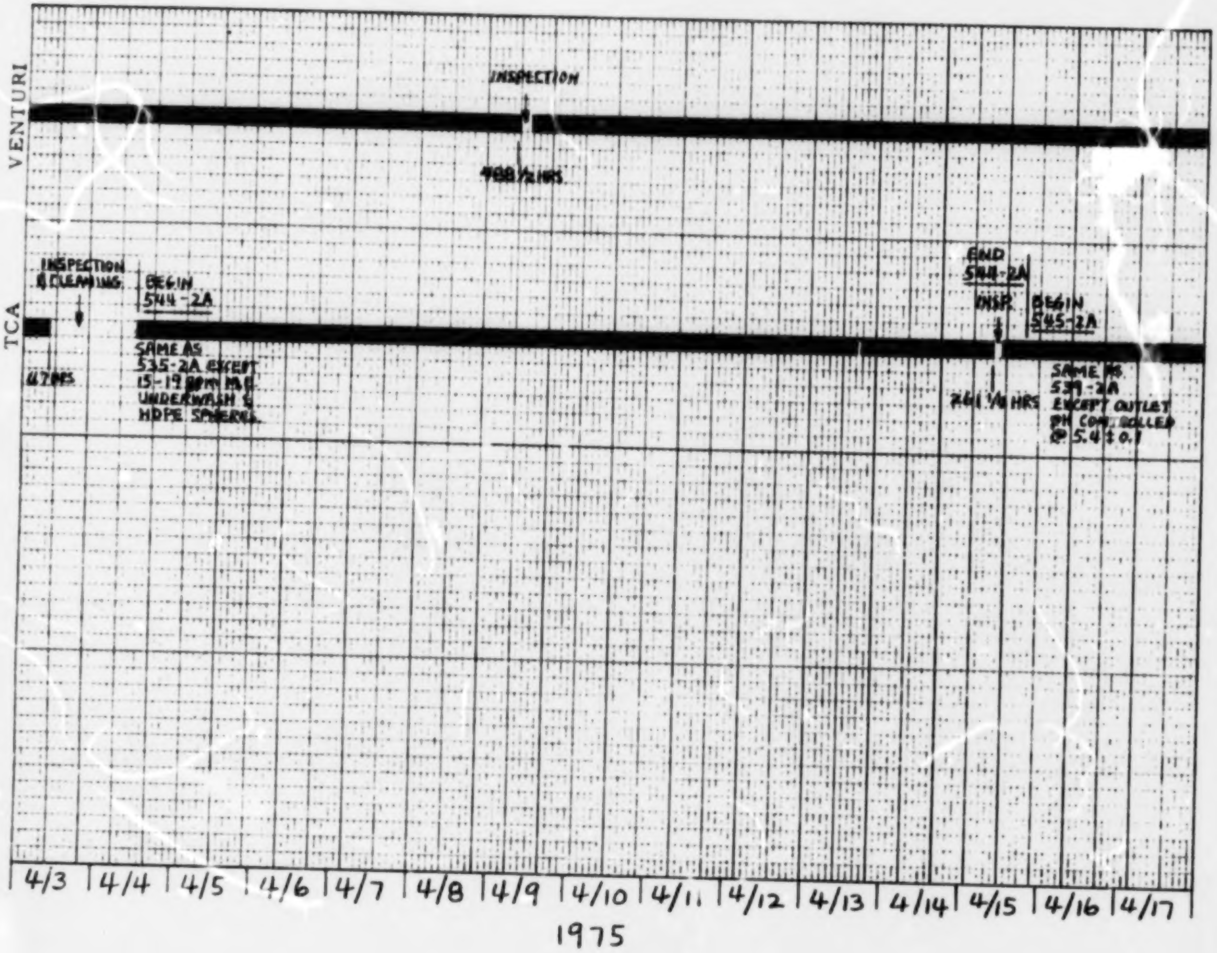

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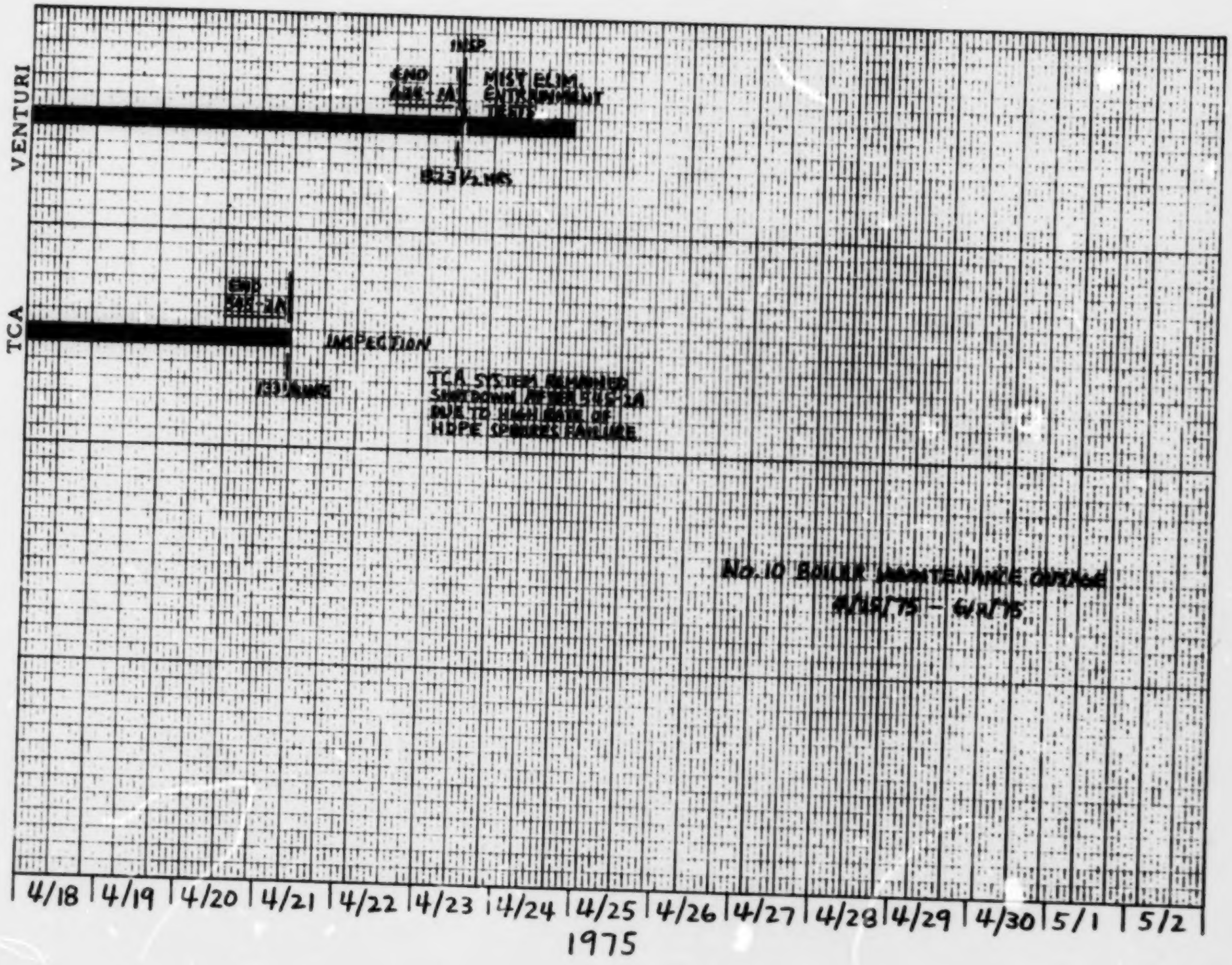


Appendix C

PROPERTIES OF RAW MATERIALS

The following is a summary of the properties of the raw materials used from October 1974 through April 1975.

C.1 COAL

Supplier: Old Ben Coal., Benton, Illinois

Type: Mixture of Old Ben mines 24 and 26 either straight from mines or reclaimed from plant coal storage pile

Analysis:

9.4	to	13.4	wt % total moisture
2.3	to	5.5	wt % sulfur
0.03	to	0.27	wt % chloride
14.7	to	27.9	wt % ash

Approximate Ash Analysis:

54 wt % SiO_2
23 wt % Al_2O_3
12 wt % Fe_2O_3
3 wt % CaO
1 wt % MgO
1 wt % SO_3
3 wt % K_2O
1 wt % Na_2O
3 wt % Ignition loss

Note: During Run 535-2B and isolated instances thereafter, Shawnee Unit No. 10 burned low sulfur western coal of the following composition:

Supplier: Western Energy Company, Cow Creek, Montana

Type: Colstrip seam

Analysis(a): 26.8 wt % total moisture
0.95 wt % sulfur
0.1 wt % chloride
10.7 wt % ash

Approximate Ash Analysis: (None made)

C.2 LIMESTONE

Supplier: Fredonia Quarries, Fredonia, Kentucky

Type: Fredonia Valley White

Analysis: 95 wt % $CaCO_3$
1 wt % $MgCO_3$
4 wt % Inerts

Grind: 97 wt % less than 325 mesh
92 wt % less than 30 microns
86 wt % less than 20 microns
53 wt % less than 6 microns

C.3 LIME

Supplier: Linwood Stone Co., Davenport, Iowa

Type: Pebble lime, unslaked

Analysis: 97.0 wt % CaO total
95.5 wt % CaO available
0.28 wt % MgO
0.47 wt % Inerts

(a) Average values, from only two analyses.

C.4 MAGNESIUM OXIDE

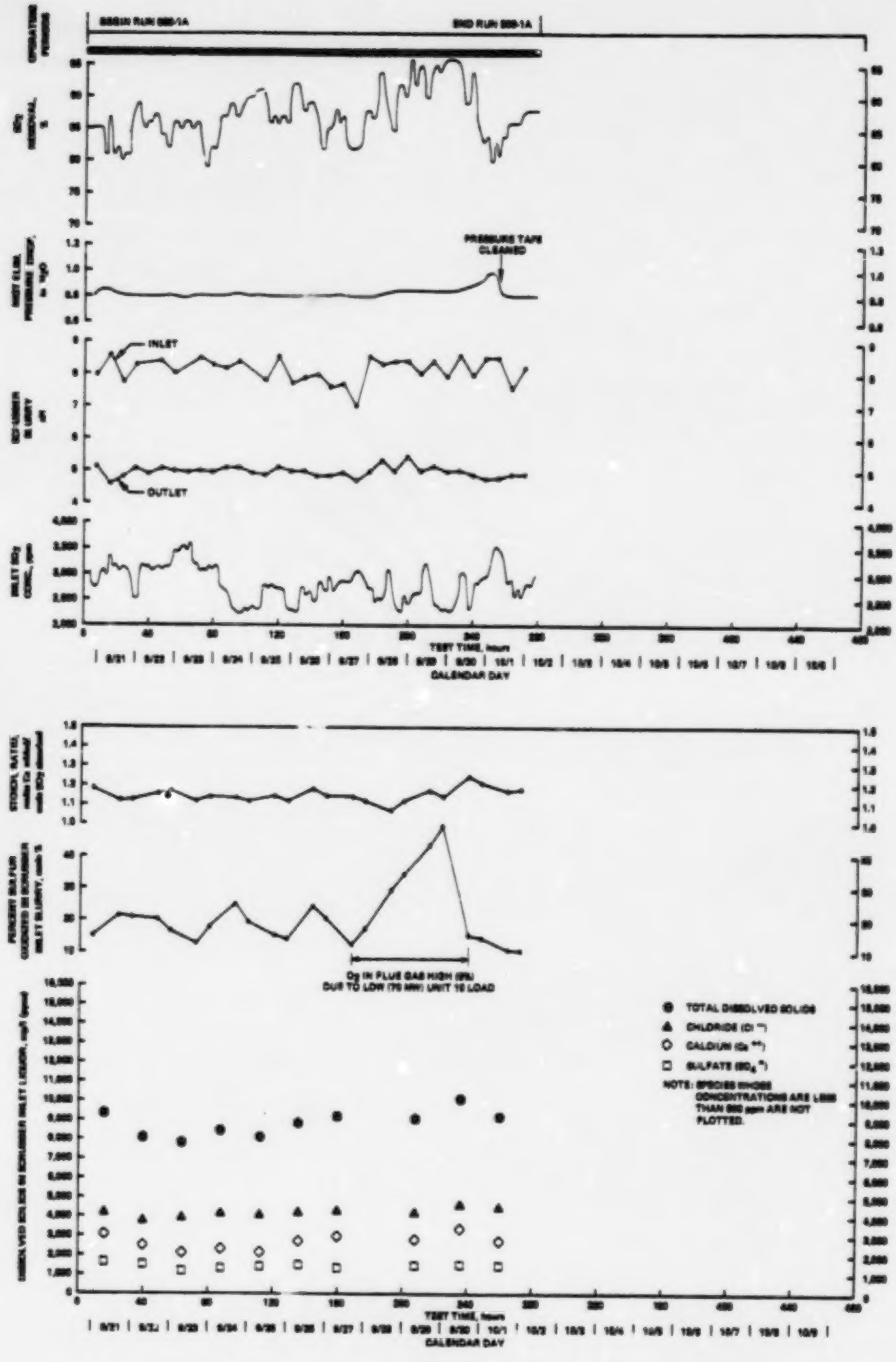
Supplier: Basic Chemicals, Ft. St. Joe, Florida

Type: MAGOX PG (pollution grade)

Analysis: 97.6 wt % MgO
1.5 wt % CaO
0.5 wt % SiO_2
0.4 wt % R_2O_3

Appendix D

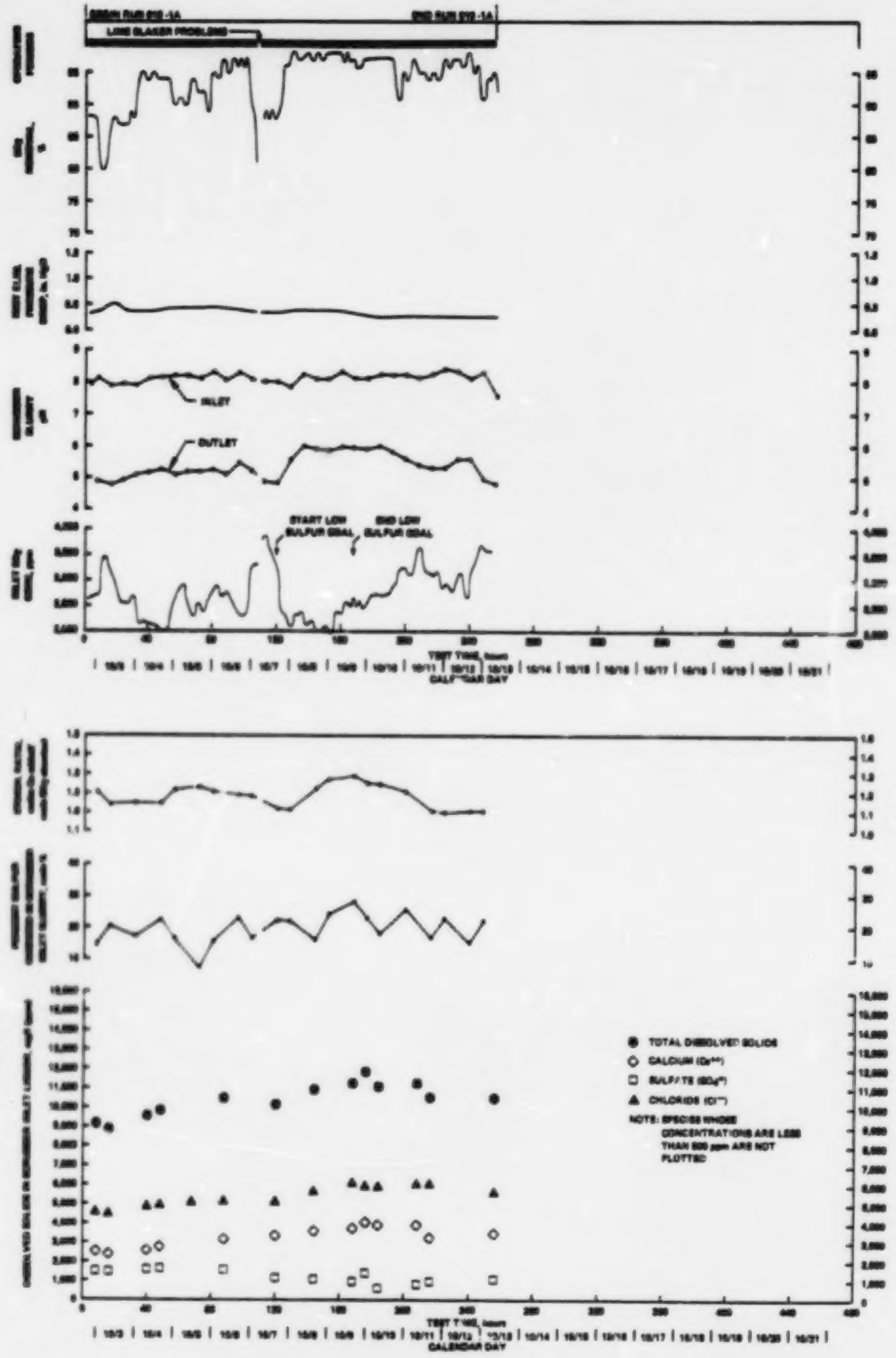
GRAPHICAL OPERATING DATA FROM VENTURI/SPRAY TOWER LIME RELIABILITY TESTS



Gas Rate = 25,000 acfm @ 330 °F
Liquor Rate to Venturi = 600 gpm
Liquor Rate to Spray Tower = 1200 gpm
Venturi L/G 30 gal/mcf
Spray Tower Gas Velocity =6.7 ft/sec
No. of Spray Headers = 4
EHT (Sealed) Residence
Time = 24 min

Percent Solids Recirculated = 7.0-8.0 wt %
Venturi Pressure Drop = 9 in H_2O
Total Pressure Drop, Excluding Mist Elim. = 11.0-11.85 in H_2O
Scrubber Inlet Liquor Temperature = 125-128 °F
Liquid Conductivity =8,000-13,000 μ mhos/cm
Discharge (Clarifier and Filter) Solids
Concentration = 47-62 wt %
Lime addition to Scrubber Downcomer

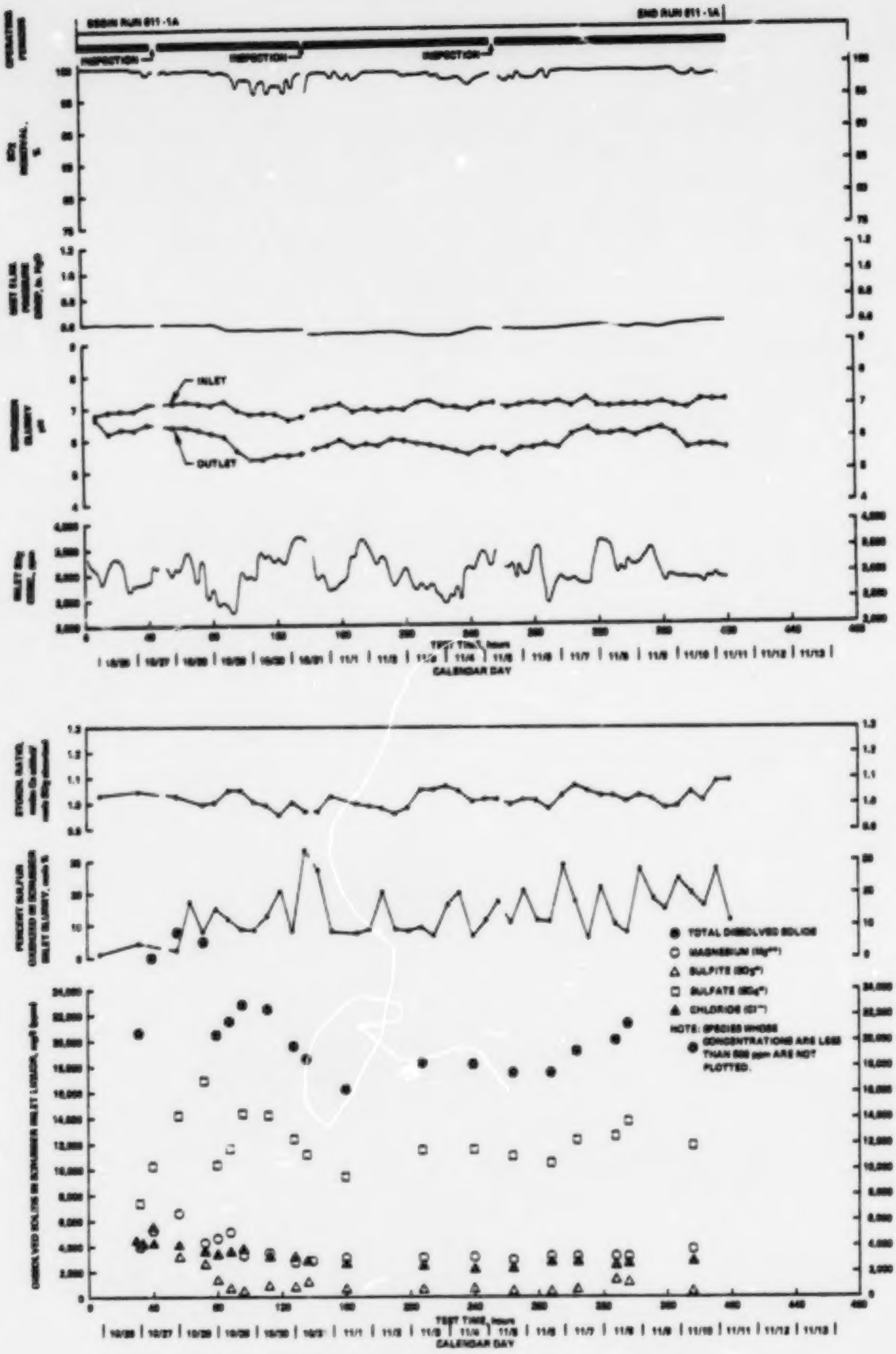
Figure D-1. Operating Data for Venturi/Spray Tower Run 609-1A



Gas Rate = 25,000 acfm @ 330° F
Liquor Rate to Venturi = 600 gpm
Liquor Rate to Spray Tower = 1200 gpm
Very Venturi L/G 30 gal/mcf
Spray Tower Gas Velocity = 6.7 ft/sec
No. of Spray Headers = 4
EHT (Sealed) Residence
Time = 24 min

Percent Solids Recirculated = 7.8-8.6 wt %
Venturi Pressure Drop = 9 in H_2O
Total Pressure Drop, Excluding Mist Elim. = 11.0-12.2 in H_2O
Scrubber Inlet Liquor Temperature = 126-130° F
Liquid Conductivity = 10,400-17,000 μ mhos/cm
Discharge (Clarifier and Filter) Solids
Concentration = 43-48 wt %
Lime addition to EHT

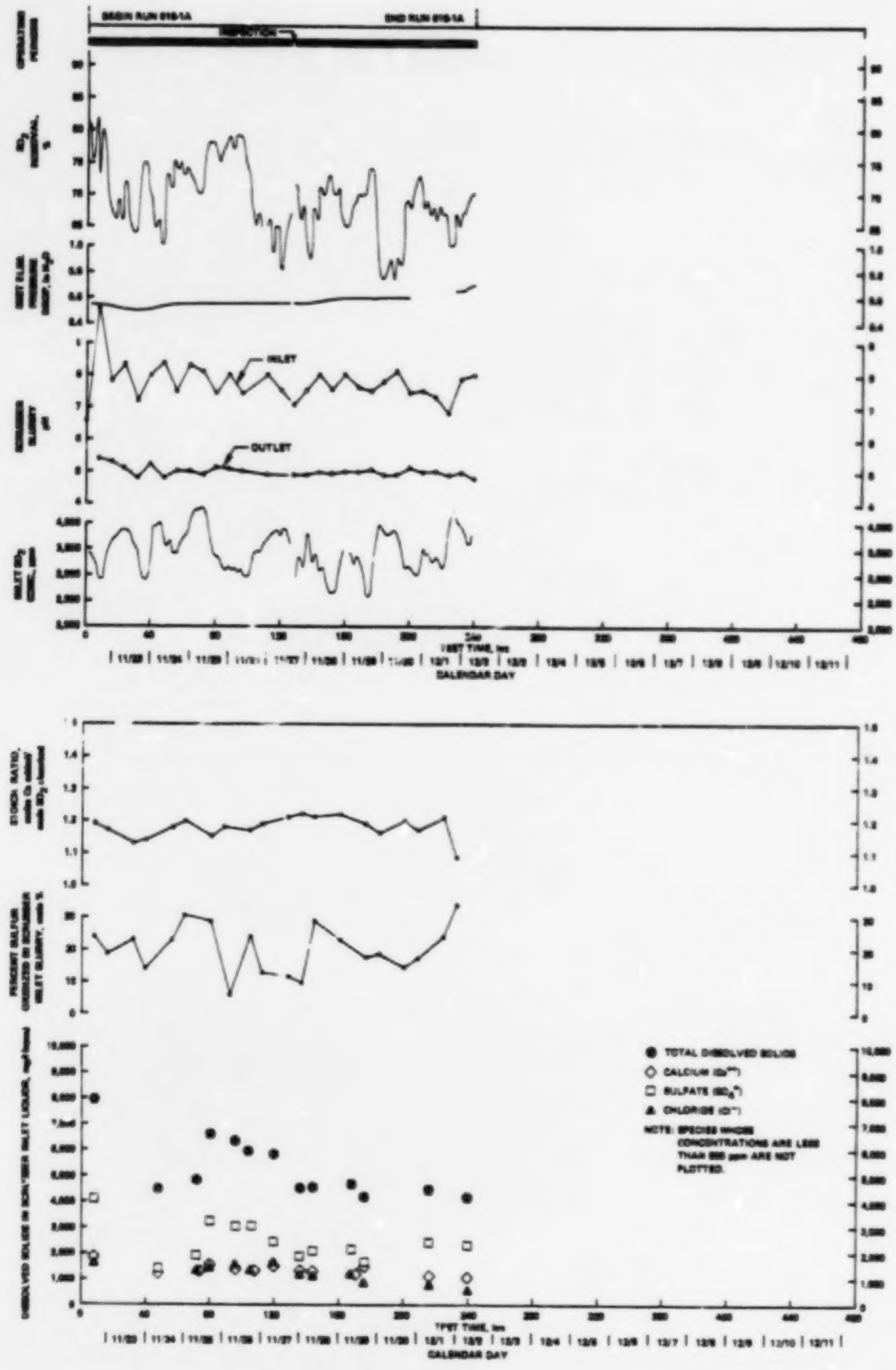
Figure D-2. Operating Data for Venturi/Spray Tower Run 610-1A



Gas Rate = 25,000 acfm @ 330° F
Liquor Rate to Venturi = 600 gpm
Liquor Rate to Spray Tower = 1200 gpm
Venturi L/G 30 gal/mcf
Spray Tower Gas Velocity = 6.7 ft/sec
No. of Spray Headers = 4
EHT (Sealed) Residence
Time = 6 min

Percent Solids Recirculated = 8.0-9.3 wt %
Venturi Pressure Drop = 9 in. H_2O
Total Pressure Drop, Excluding Mist Elim. = 10.4-12.0 in H_2O
Scrubber Inlet Liquor Temperature = 127-131 ° F
Liquid Conductivity = 9,200-13,000 µ mhos/cm
Discharge (Clarifier and Filter) Solids
Concentration = 44-48 wt %
Lime addition to Scrubber Downcomer

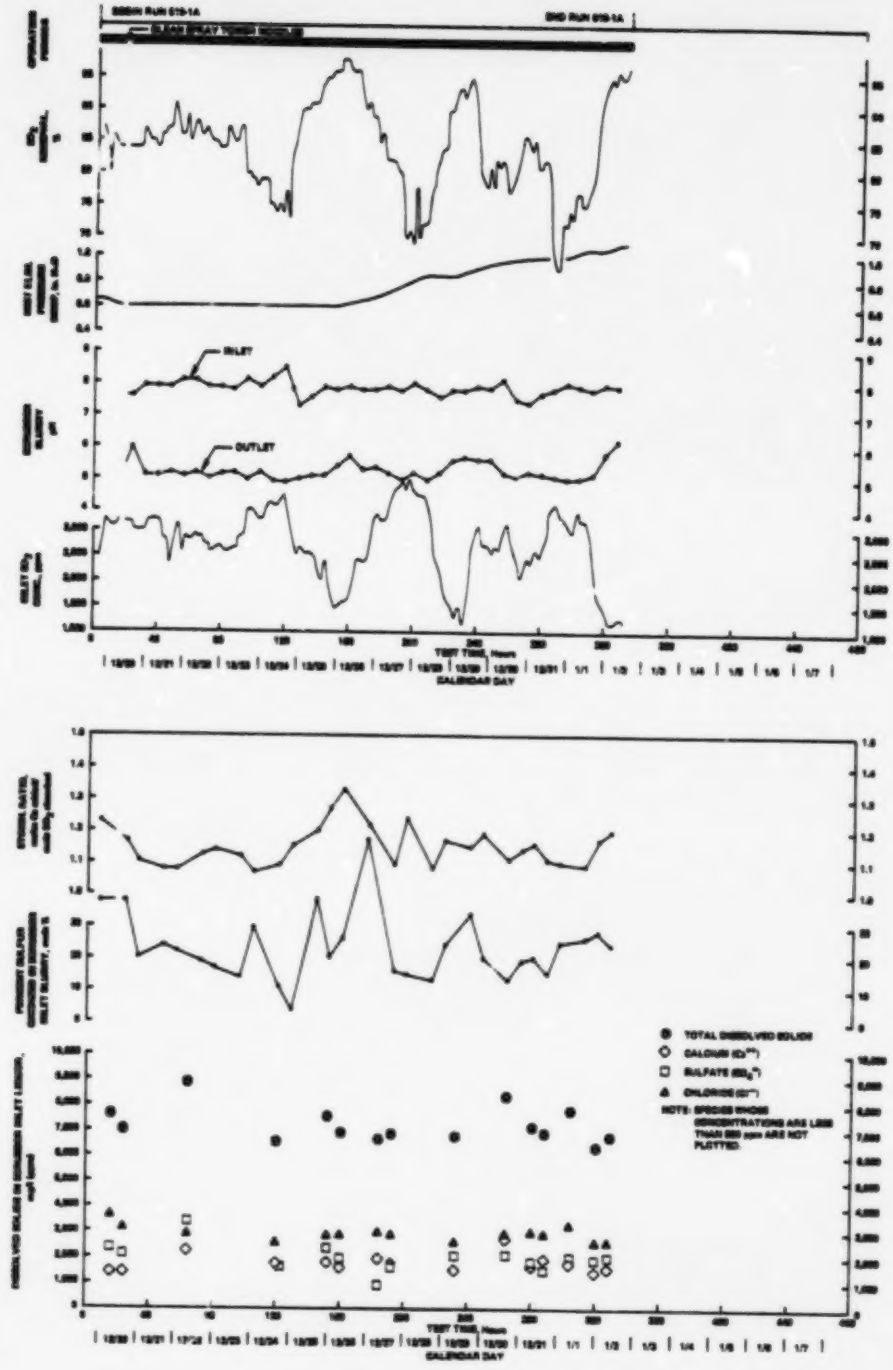
Figure D-3. Operating Data for Venturi/Spray Tower Run 611-1A



Gas Rate = 25,000 acfm @ 330° F
Liquor Rate to Venturi = minimum (100 gpm)
Liquor Rate to Spray Tower = 1200 gpm
Venturi L/G = 5 gal/mcf
Spray Tower Gas Velocity = 6.7 ft/sec.
No. of Spray Headers = 4
EHT (Sealed) Residence Time = 17 min
(11/22-11/25), 12 min (after 11/25)

Percent Solids Recirculated = 7.5-8.8 wt %
Venturi Plug position 100 % Open
Total Pressure Drop, Excluding Mist Elim. = 3.8-4.2 in H_2O
Scrubber Inlet Liquor Temperature = 124-130° F
Liquid Conductivity = 4,300-5,800 μ mhos/cm
Discharge (Clarifier) Solids
Concentration = 16-21 wt %
Lime addition to Scrubber Downcomer

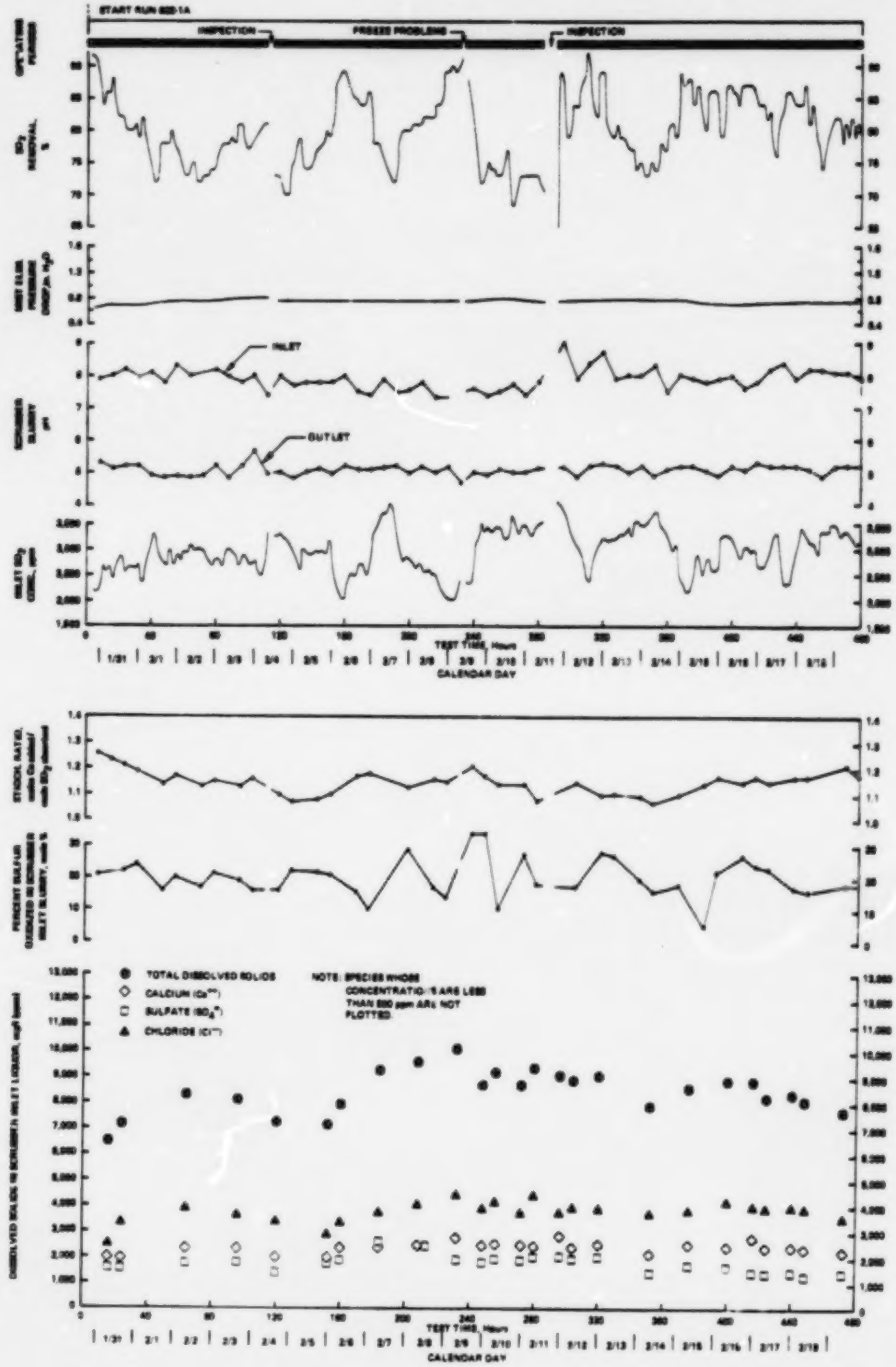
'gure D-4. Operating Data for Venturi/Spray Tower Run 618-1A



Gas Rate = 25,000 acfm @ 330 °F
Liquid Rate to Venturi = 800 gpm
Liquor Rate to Spray Tower = 1200 gpm
Venturi L/G = 30 gal/mcf
Spray Tower L/G = 60 gal/mcf
Spray Tower Gas Velocity = 6.7 ft/sec
No. of Spray Headers = 4
EHT Residence Time = 12 min

Percent Solids Recirculated = 7-10 wt %
Venturi Pressure Drop = 9 in H_2O
Total Pressure Drop, Excluding Mist Elim. =10.8-12.0 in H_2O
Scrubber Inlet Liquor Temperature = 118-128 °F
Liquid Conductivity = 3,700-7,800 μ mhos/cm
Discharge (Clarifier and Filter) Solids
Concentration = 53-60 wt %
Lime Addition to Scrubber Downcomer

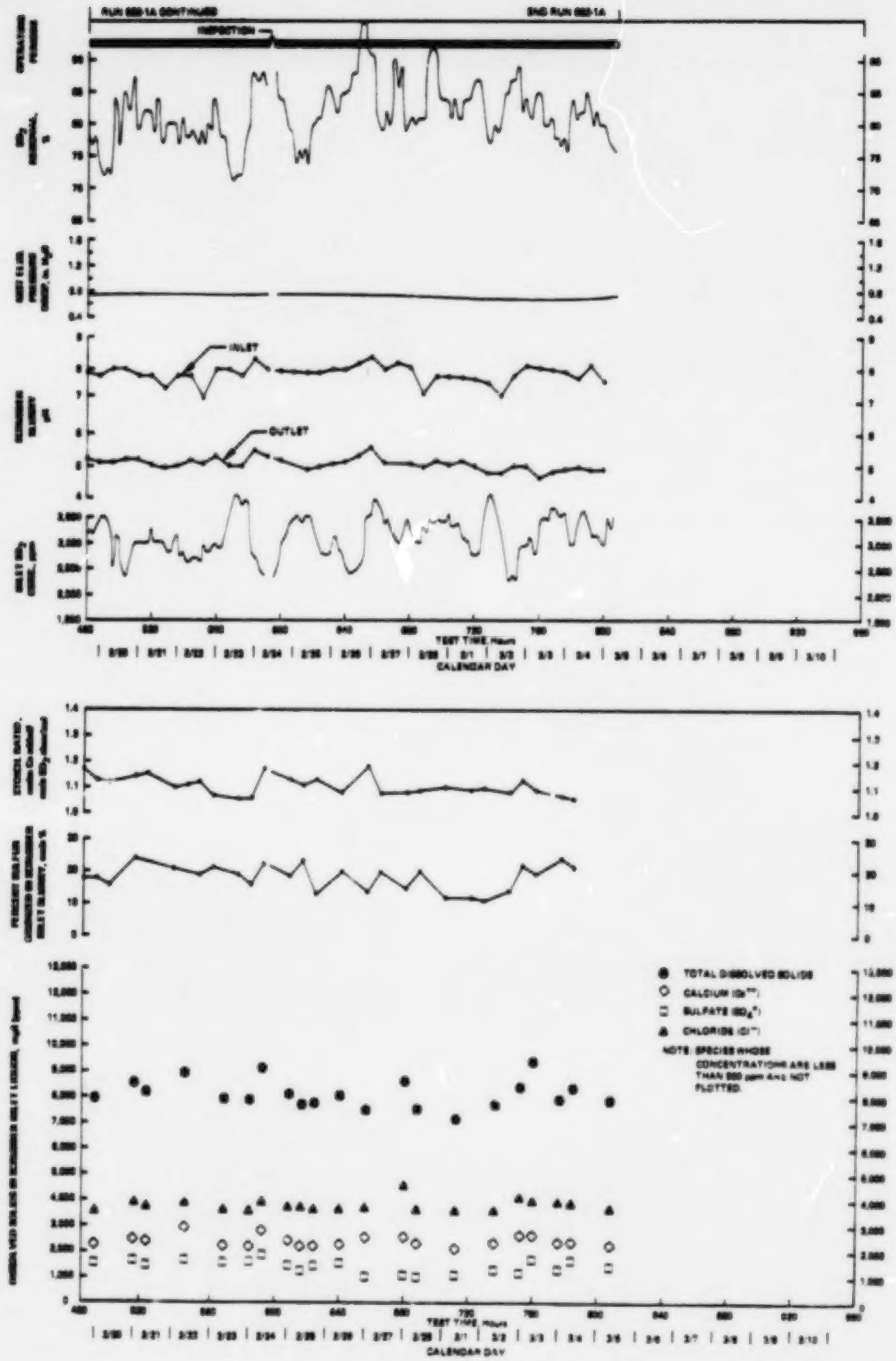
Figure D-5. Operating Data for Venturi/Spray Tower Run 619-1A



Gas Rate = 25,000 acfm @ 330 °F
Liquid Rate to Venturi = 600 gpm
Liquor Rate to Spray Tower = 1200 gpm
Venturi L/G = 30 gal/mcf
Spray Tower L/G = 60 gal/mcf
Spray Tower Gas Velocity = 6.7 ft/sec
No. of Spray Headers = 4
EHT Residence Time = 17 min

Percent Solids Recirculated = 7-8 wt %
Venturi Pressure Drop = 9 in H_2O
Total Pressure Drop, Excluding Mist Elim. = 11-12 in H_2O
Scrubber Inlet Liquor Temperature = 123-127 °F
Liquid Conductivity = 6,100-6,700 μ mhos/cm
Discharge (Clarifier and Filter) Solids
Concentration = 52-60 wt %
Lime Addition to Scrubber Downcomer

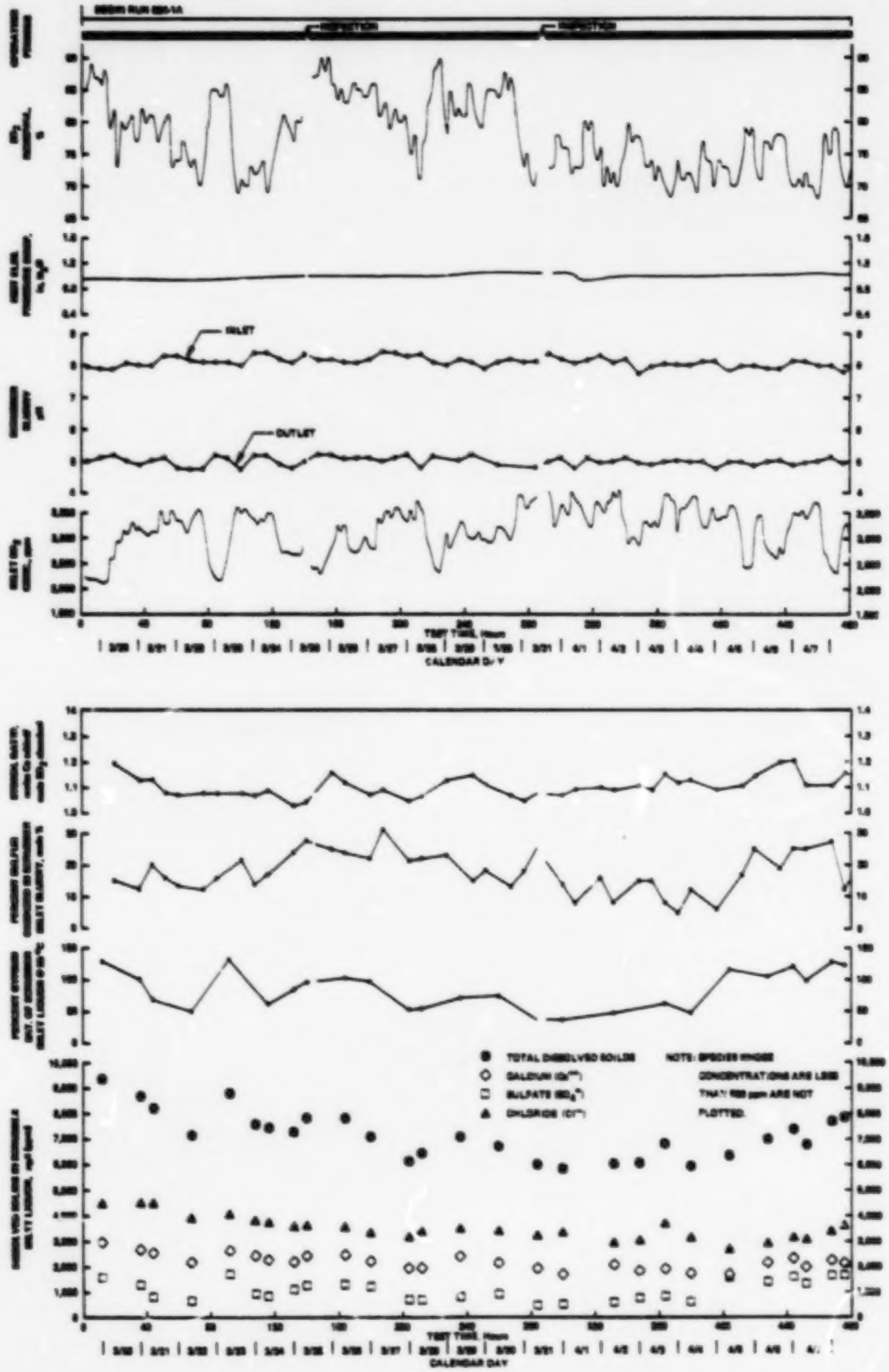
Figure D-6. Operating Data for Venturi/Spray Tower Run 622-1A



Gas Rate = 25,000 acfm @ 330 °F
Liquid Rate to Venturi = 600 gpm
Liquor Rate to Spray Tower = 1200 gpm
Venturi L/G = 30 gal/mcf
Spray Tower L/G = 60 gal/mcf
Spray Tower Gas Velocity = 6.7 ft/sec
No. of Spray Headers = 4
EHT Residence Time = 17 min

Percent Solids Recirculated = 7.4-8.7 wt %
Venturi Pressure Drop = 9 in H_2O
Total Pressure Drop, Excluding Mist Elim. = 11.5-12.5 in H_2O
Scrubber Inlet Liquor Temperature = 124-128 °F
Liquid Conductivity = 5,400-8,400 µ mhos/cm
Discharge (Clarifier and Filter) Solids
Concentration = 50-56 wt %
Lime Addition to Scrubber Downcomer

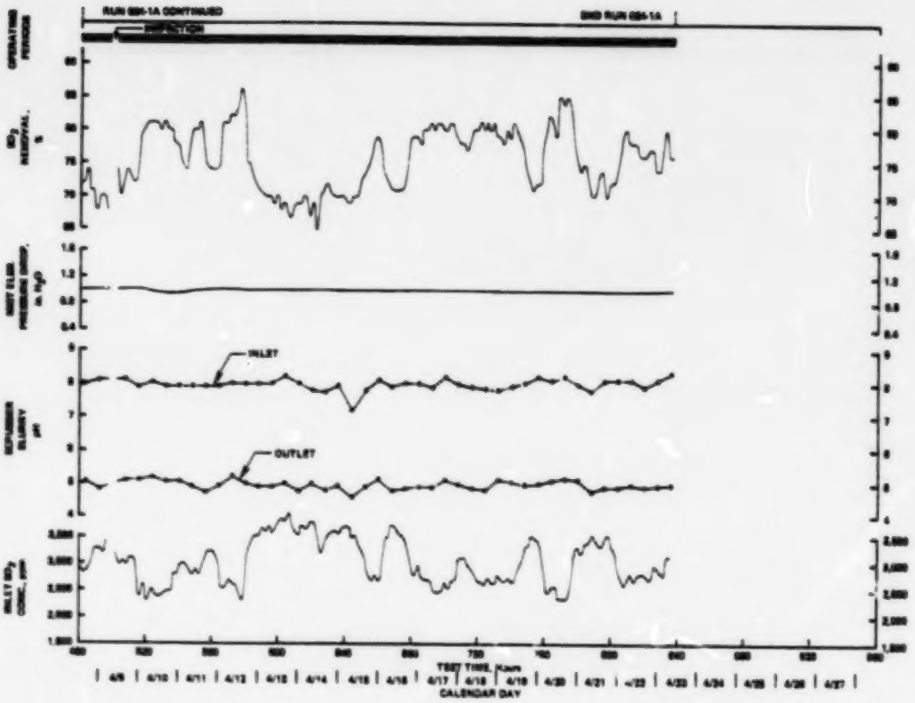
Figure D-6. Operating Data for Venturi/Spray Tower Run 622-1A (continued)

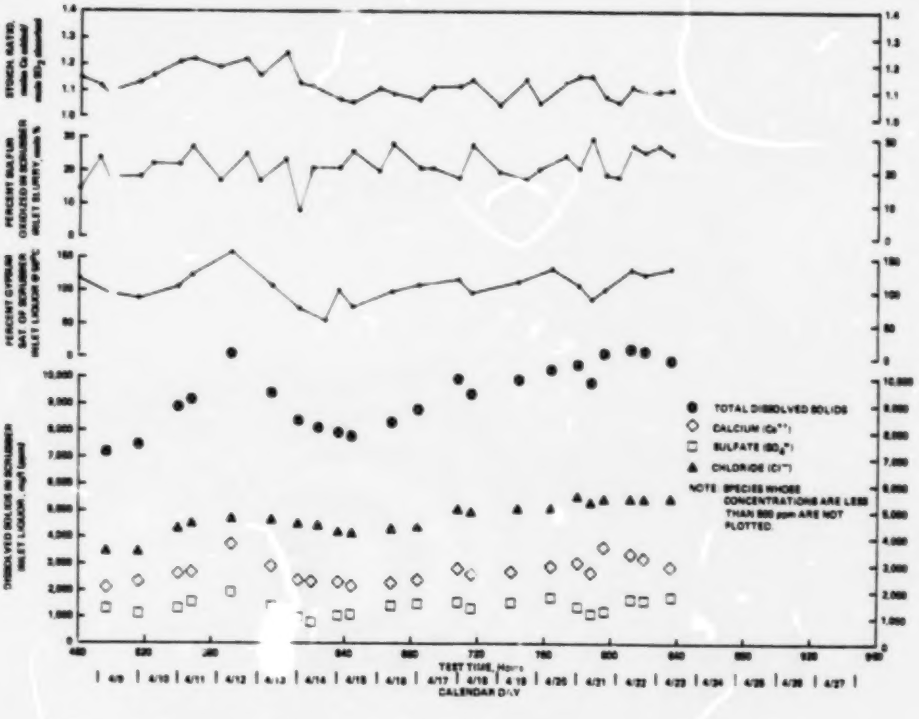


Gas Rate = 30,000 acfm @ 330 °F
Liquor Rate to Venturi = 600 gpm
Liquor Rate to Spray Tower = 1200 gpm
Venturi L/G = 25 gal/mcf
Spray Tower L/G = 50 gal/mcf
Spray Tower Gas Velocity = 8.0 ft/sec
No. of Spray Headers = 4
EHT Residence Time = 17 min

Percent Solids Recirculated = 7-10 wt %
Venturi Pressure Drop = 9 in H_2O
Total Pressure Drop, Excluding Mist Elim. = 12.5-12.8 in H_2O
Scrubber Inlet Liquor Temperature = 120-128 °F
Liquid Conductivity = 6,100-10,000 μ mhos/cm
Discharge (Clarifier and Filter) Solids
Concentration = 48-64 wt %
Lime Addition to Scrubber Downcomer

Figure D-7. Operating Data for Venturi/Spray Tower Run 624-1A





Gas Rate = 30,000 acfm @ 330 °F
Spray Tower Gas Velocity = 8.0 ft/sec
Liquor Rate to Venturi = 600 gpm
Liquor Rate to Spray Tower = 1200 gpm
Venturi L/G = 25 gal/mcf
Spray Tower L/G = 50 gal/mcf
No. of Spray Headers = 4
EHT Residence Time = 17 min

Percent Solids Recirculated = 7-10 wt %
Venturi Pressure Drop = 9 in H_2O
Total Pressure Drop, Excluding Mist Elim. = 12.0-12.4 in H_2O
Scrubber Inlet Liquor Temperature = 120-129 °F
Liquid Conductivity = 8,200-14,000 μ mhos/cm
Discharge (Clarifier and Centrifuge) Solids
Concentration = 48-58 wt %
Lime Addition to Scrubber Downcomer

Figure D-7. Operating Data for Venturi/Spray Tower Run 624-1A (continued)

Appendix E

AVERAGE LIQUOR COMPOSITIONS FOR VENTURI/SPRAY TOWER LIME RELIABILITY TESTS

Table E-1

AVERAGE LIQUOR COMPOSITIONS FOR VENTURI/SPRAY TOWER LIME RUN 609-1A

Sample Point	pH	Liquor Species Concentrations, mg/l (ppm)									Calculated Percent[b] Sulfate Saturation
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$SO_3^{=}$	$SO_4^{=}$	$CO_3^{=}$	Cl^{-}	Total	
Scrubber Inlet	8.00	2680	310	60	120	40	1440	20	4200	8870	110
Scrubber Outlet	5.00	2700	360	60	120	390	1660	5	4350	9650	125
Clarifier Overflow[a]	8.60	2200	260	60	110	30	1620	15	3930	8230	115

Notes: The values in this table are averages for steady state operation.
Solids Disposal System: Clarifier and filter.
The following ranges of values were observed during the run.
Percent sulfur oxidized: 12-30
Loop closure, percent solids discharged: 47-52

[a] Process water hold tank.

[b] (activity Ca^{++}) x (activity $SO_4^{=}$) / (solubility product at 50°C). Estimated solubility product for $CaSO_4 \cdot 2H_2O$ at 50°C is 2.2×10^{-5} (Radian Corporation, "A Theoretical Description of the Limestone-Injection Wet Scrubbi[illegible] Process", NAPCA Report, June 9, 1970).

Table E-1 (continued)

AVERAGE LIQUOR COMPOSITIONS FOR VENTURI/SPRAY TOWER LIME RUN 610-1A

Sample Point	pH	Liquor Species Concentrations, mg/l (ppm)									Calculated Percent[b] Sulfate Saturation
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$SO_3^{=}$	$SO_4^{=}$	$CO_3^{=}$	Cl^{-}	Total	
Scrubber Inlet	8.1	3100	200	80	150	60	1350	20	5200	10,000	110[c]
Scrubber Outlet	4.9	2800	280	90	150	110	2300	8	4300	10,000	180[d]
Clarifier Overflow[a]	8.3	2700	180	80	130	50	1600	20	4600	9500	120

Notes: The values in this table are averages for steady state operating period from 10/2/74 through 10/8/74.
Solids Disposal System: Clarifier and filter.
The following ranges of values were observed during the run.
Percent sulfur oxidized: 16-26
Loop closure, percent solids discharged: 43-48

(a) Process water hold tank.

(b) (activity Ca^{++}) x (activity $SO_4^{=}$) / (solubility product at 50°C). Estimated solubility product for $CaSO_4 \cdot 2H_2O$ at 50°C is 2.2×10^{-5} (Radian Corporation, "A Theoretical Description of the Limestone-Injection Wet Scrubbing Process", NAPCA Report, June 9, 1970).

(c) At an average inlet SO_2 concentration of 2500 ppm.

(d) Value from one analysis.

Table E-1 (continued)

AVERAGE LIQUOR COMPOSITIONS FOR VENTURI/SPRAY TOWER LIME RUN 611-1A

Sample Point	pH	Liquor Species Concentrations, mg/l (ppm)									Calculated Percent[a] Sulfate Saturation
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$SO_3^{=}$	$SO_4^{=}$	$CO_3^{=}$	Cl^{-}	Total	
Scrubber Inlet	7.0	320	3200	60	80	510	11,000	100	2500	17,700	45[b]
Scrubber Outlet	5.85	600	3200	60	110	880	12,300	12	2500	18,000	95
Mist Eliminator Wash	7.55	320	2700	60	85	130	10,000	100	2000	15,400	50

Notes: The values in this table are averages for steady state operation.
Solids Disposal System: Clarifier and filter.
The following ranges of values were observed during the run.
Percent sulfur oxidized: 15-28
Loop closure, percent solids discharged: 44-49

[a] (activity Ca^{++}) x (activity $SO_4^{=}$) / (solubility product at 50°C). Estimated solubility product for $CaSO_4 \cdot 2H_2O$ at 50°C is 2.2×10^{-5} (Radian Corporation, "A Theoretical Description of the Limestone-Injection Wet Scrubbing Process", NAPCA Report, June 9, 1970).

[b] At an average inlet SO_2 concentration of 3000 ppm.

Table E-1 (continued)

AVERAGE LIQUOR COMPOSITIONS FOR VENTURI/SPRAY TOWER LIME RUN 618-1A

Sample Point	pH	Liquor Species Concentrations, mg/l (ppm)									Calculated Percent Sulfate Saturation at 50°C[(a)]
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$SO_3^{=}$	$SO_4^{=}$	$CO_3^{=}$	Cl^{-}	Total	
Scrubber Inlet	7.70	1250	95	20	50	35	2100	15	1130	4695	140
Scrubber Outlet	4.90	1600	90	25	50	1050	2400	2	1250	6467	170
Clarifier Overflow	7.60	1250	85	25	50	20	1700	10	1280	4420	115

Notes: The values in this table are averages for steady state operation.
Solids Disposal System: Clarifier.
The following ranges of values were observed during the run.
Percent sulfur oxidized: 10-28
Loop closure, percent solids discharged: 16-21

(a) (activity Ca^{++}) x (activity $SO_4^{=}$) / (solubility product at 50°C). Estimated solubility product for $CaSO_4 \cdot 2H_2O$ at 50°C is 2.2×10^{-5} (Radian Corporation, "A Theoretical Description of the Limestone-Injection Wet Scrubbing Process", NAPCA Report, June 9, 1970).

Table E-1 (continued)

AVERAGE LIQUOR COMPOSITIONS FOR VENTURI/SPRAY TOWER LIME RUN 619-1A

Sample Point	pH	Liquor Species Concentrations, mg/l (ppm)									Calculated Percent Sulfate Saturation at 50°C[a]
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$SO_3^{=}$	$SO_4^{=}$	$CO_3^{=}$	Cl^{-}	Total	
Scrubber Inlet	7.80	1860	330	40	115	40	1830	25	2920	7200	125
Scrubber Outlet	5.30	1930	370	40	120	630	2270	15	2900	8300	145
Clarifier Overflow	8.45	1360	320	45	110	50	1830	40	2480	6600	105

Notes: The values in this table are averages for steady state operation.
Solids Disposal System: Clarifier and Filter.
The following ranges of values were observed during the run.
Percent sulfur oxidized: 14-34
Loop closure, percent solids discharged: 53-60

[a] (activity Ca^{++}) x (activity $SO_4^{=}$)/(solubility product at 50°C). Estimated solubility product for $CaSO_4 \cdot 2H_2O$ at 50°C is 2.2×10^{-5} (Radian Corporation, "A Theoretical Description of the Limestone-Injection Wet Scrubbing Process", NAPCA Report, June 9, 1970).

Table E-1 (continued)

AVERAGE LIQUOR COMPOSITIONS FOR VENTURI/SPRAY TOWER LIME RUN 622-1A

Sample Point	pH	Liquor Species Concentrations, mg/l (ppm)									Calculated Percent Sulfate Saturation at 50°C[a]
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$SO_3^{=}$	$SO_4^{=}$	$CO_3^{=}$	Cl^{-}	Total	
Scrubber Inlet	7.70	2440	270	60	125	50	1600	20	3850	8400	115
Scrubber Outlet	5.00	2630	280	60	125	740	1830	10	3860	9500	135
Clarifier Overflow	7.95	2410	270	60	120	40	1660	25	3740	8300	125

Notes: The values in this table are averages for steady state operation.
Solids Disposal System: Clarifier and Filter.
The following ranges of values were observed during the run.
Percent sulfur oxidized: 12-28
Loop closure, percent solids discharged: 50-62

[a] (activity Ca^{++}) x (activity $SO_4^{=}$)/(solubility product at 50°C). Estimated solubility product for $CaSO_4 \cdot 2H_2O$ at 50°C is 2.2×10^{-5} (Radian Corporation, "A Theoretical Description of the Limestone-Injection Wet Scrubbing Process". NAPCA Report, June 9, 1970).

Table E-1 (continued)

AVERAGE LIQUOR COMPOSITIONS FOR VENTURI/SPRAY TOWER LIME RUN 623-1A

Sample Point	pH	Liquor Species Concentrations, mg/l (ppm)									Calculated Percent Sulfate Saturation at 50°C[a]
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$SO_3^{=}$	$SO_4^{=}$	$CO_3^{=}$	Cl^{-}	Total	
Scrubber Inlet	8.00	2350	230	55	125	50	1350	14	3460	7600	105
Scrubber Outlet	4.95	2590	250	55	125	640	1690	9	3600	9000	130
Clarifier Overflow	8.15	2370	290	55	125	45	1430	16	1250	7600	110

Notes: The values in this table are averages for steady state operation.
Solids Disposal System: Clarifier and Centrifuge.
The following ranges of values were observed during the run.
Percent sulfur oxidized: 11-21
Loop closure, percent solids discharged: 53-60

[a] (activity Ca^{++}) x (activity $SO_4^{=}$)/(solubility product at 50°C). Estimated solubility product for $CaSO_4 \cdot 2H_2O$ at 50°C is 2.2×10^{-5} (Radian Corporation, "A Theoretical Description of the Limestone-Injection Wet Scrubbing Process", NAPCA Report, June 9, 1970).

Table E-1 (continued)

AVERAGE LIQUOR COMPOSITIONS FOR VENTURI/SPRAY TOWER LIME RUN 624-1A

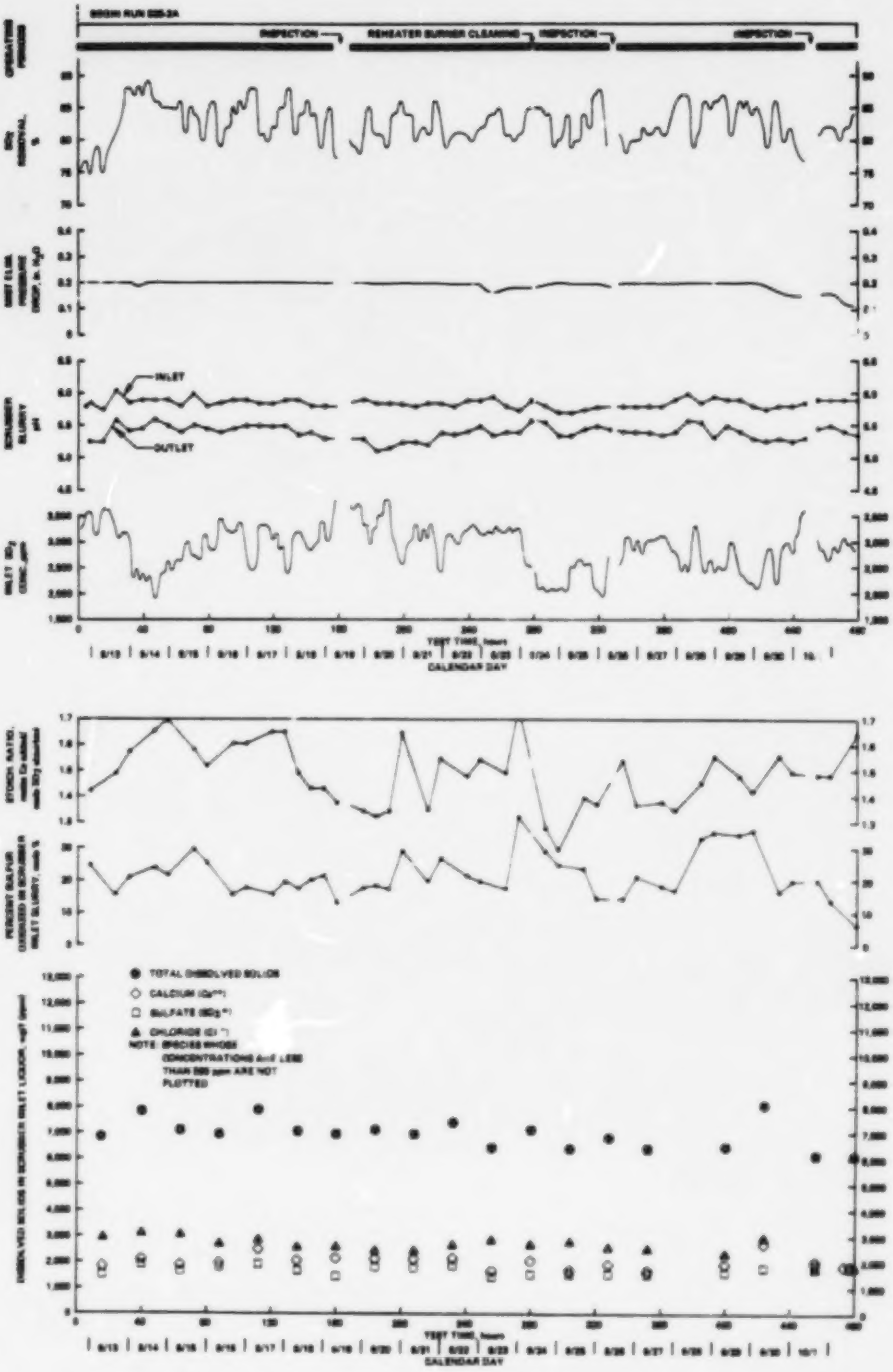
Sample Point	pH	Liquor Species Concentrations, mg/l (ppm)									Calculated Percent Sulfate Saturation at 50°C[(a)]
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$SO_3^{=}$	$SO_4^{=}$	$CO_3^{=}$	Cl^{-}	Total	
Scrubber Inlet	8.05	2420	230	55	115	65	1220	7	4010	8100	95
Scrubber Outlet	4.95	2620	260	50	115	710	1580	6	3990	9300	120
Clarifier Overflow	8.30	2420	230	50	110	60	1320	8	3870	8070	100

Notes: The values in this table are averages for the steady state operating period.
Solids Disposal System: Clarifier and Centrifuge.
The following ranges of values were observed during the run.
Percent sulfur oxidized: 12-30
Loop closure, percent solids discharged: 48-58

(a) (activity Ca^{++}) x (activity $SO_4^{=}$)/(solubility product at 50°C). Estimated solubility product for $CaSO_4 \cdot 2H_2O$ at 50°C is 2.2×10^{-5} (Radian Corporation, "A Theoretical Description of the Limestone-Injection Wet Scrubbing Process", NAPCA Report, June 9, 1970).

Appendix F

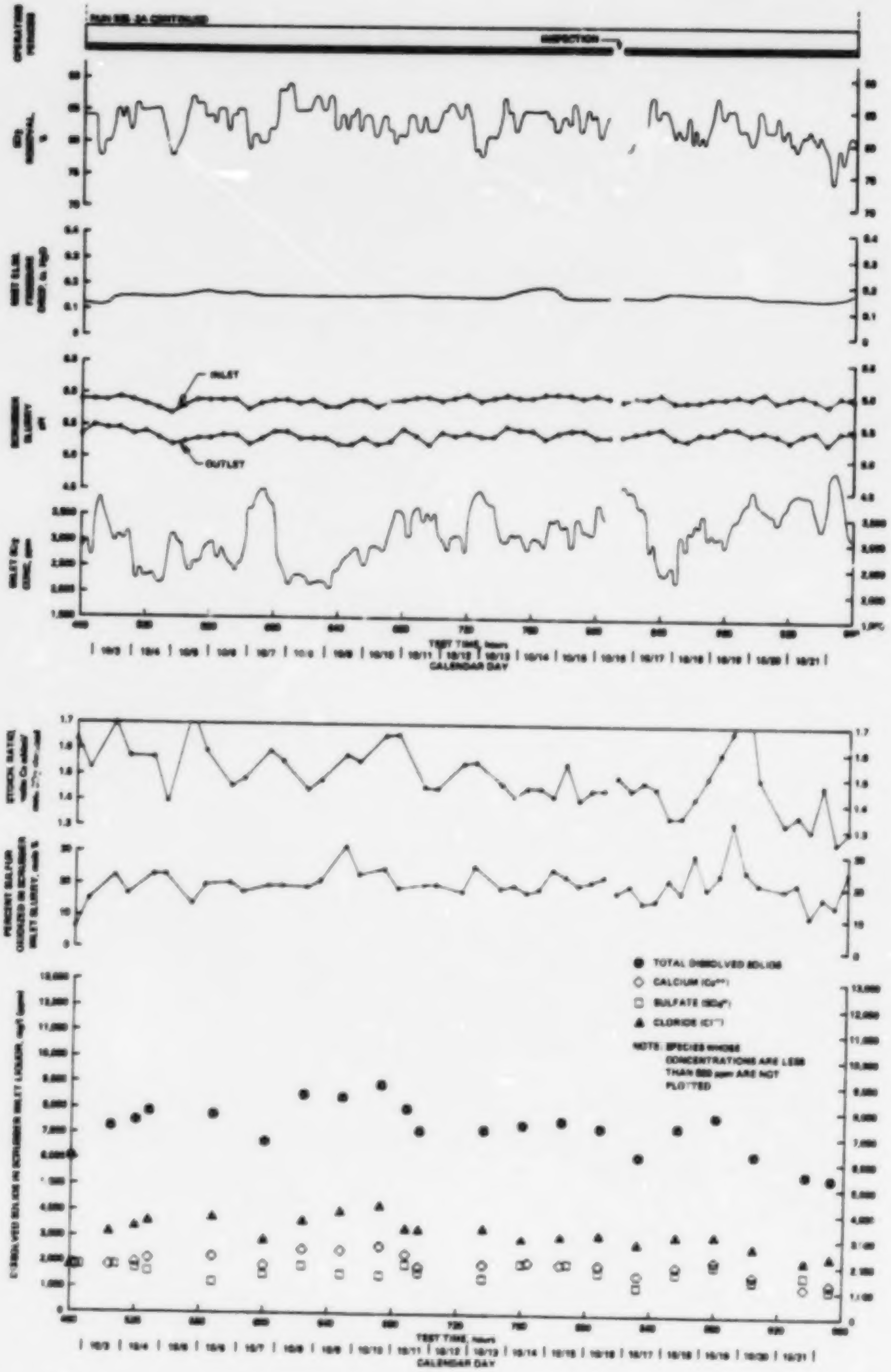
GRAPHICAL OPERATING DATA FROM TCA LIMESTONE RELIABILITY TESTS



Gas Rate = 20,500 acfm @ 300 °F
Liquor Rate = 1200 gpm
L/G = 73 gal/mcf
Gas Velocity = 8.6 ft/sec
EHT (Sealed) Residence Time = 12 min (9/12-9/27),
15 min (after 9/27)
Three Stages, 5 in spheres/stage

Percent Solids Recirculated = 12-15 wt %
Total Pressure Drop, Excluding Mist Elim.
and Koch Tray = 4.0-4.6 in H_2O
Scrubber Inlet Liquor Temperature = 120-126 °F
Liquid Conductivity = 4,800-10,000 μ mhos/cm
Discharge (Clarifier) Solids
Concentration = 38-42 wt %

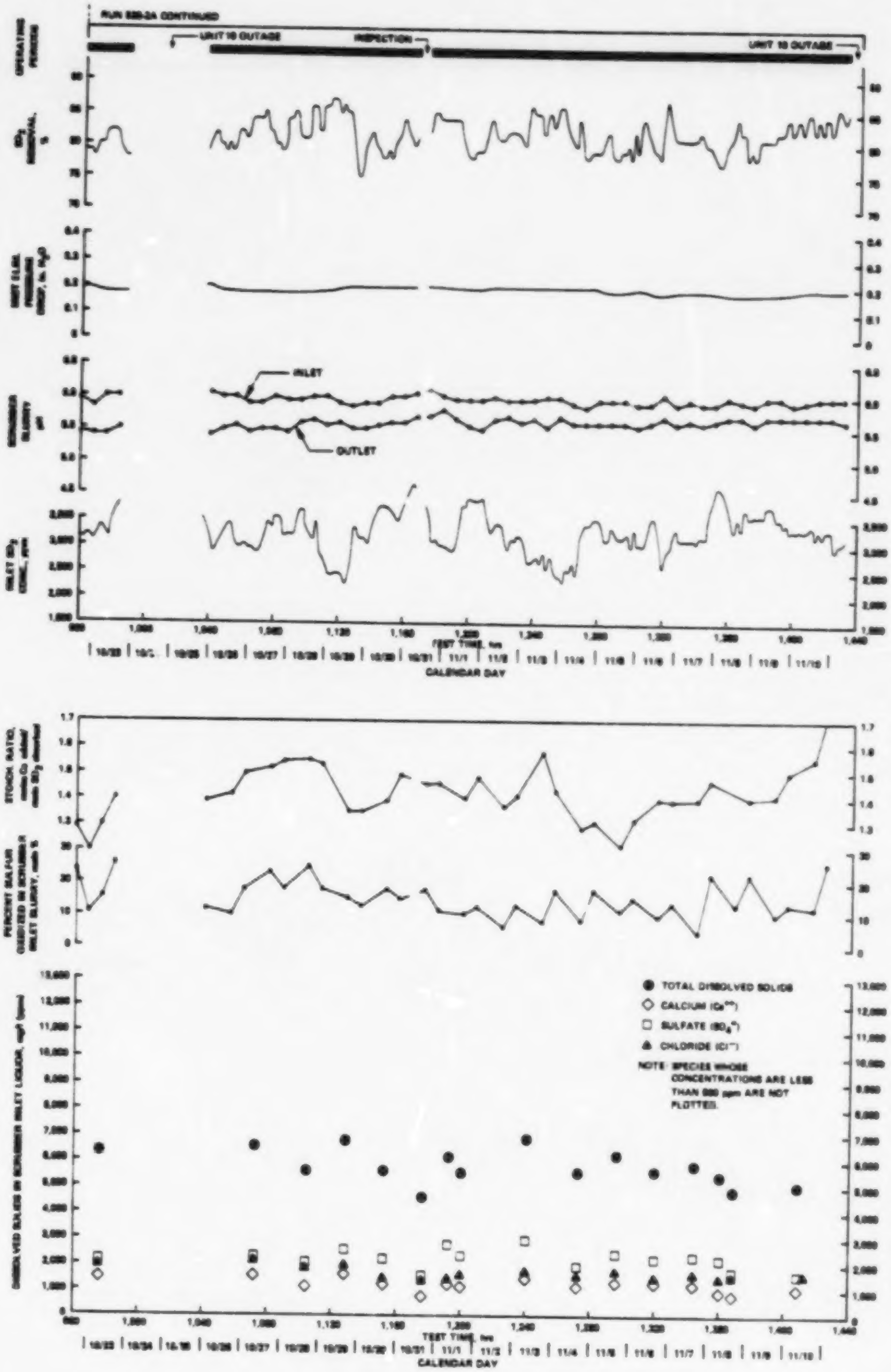
Figure F-1. Operating Data for TCA Run 535-2A



Gas Rate = 20,500 acfm @ 300° F
Liquor Rate = 1200 gpm
L/G = 73 gal/mcf
Gas Velocity = 8.6 ft/sec
EHT (Sealed) Residence Time = 12 min (9/12/27),
15 min (after 9/27)
Three Stages, 5 in spheres/stage

Percent Solids Recirculated = 12-15 wt %
Total Pressure Drop, Excluding Mist Elim.
and Koch Tray = 4.0-4.6 in H_2O
Scrubber Inlet Liquor Temperature = 121-128° F
Liquid Conductivity = 8,600-11,800 µ mhos/cm
Discharge (Clarifier) Solids
Concentration = 35-42 wt %

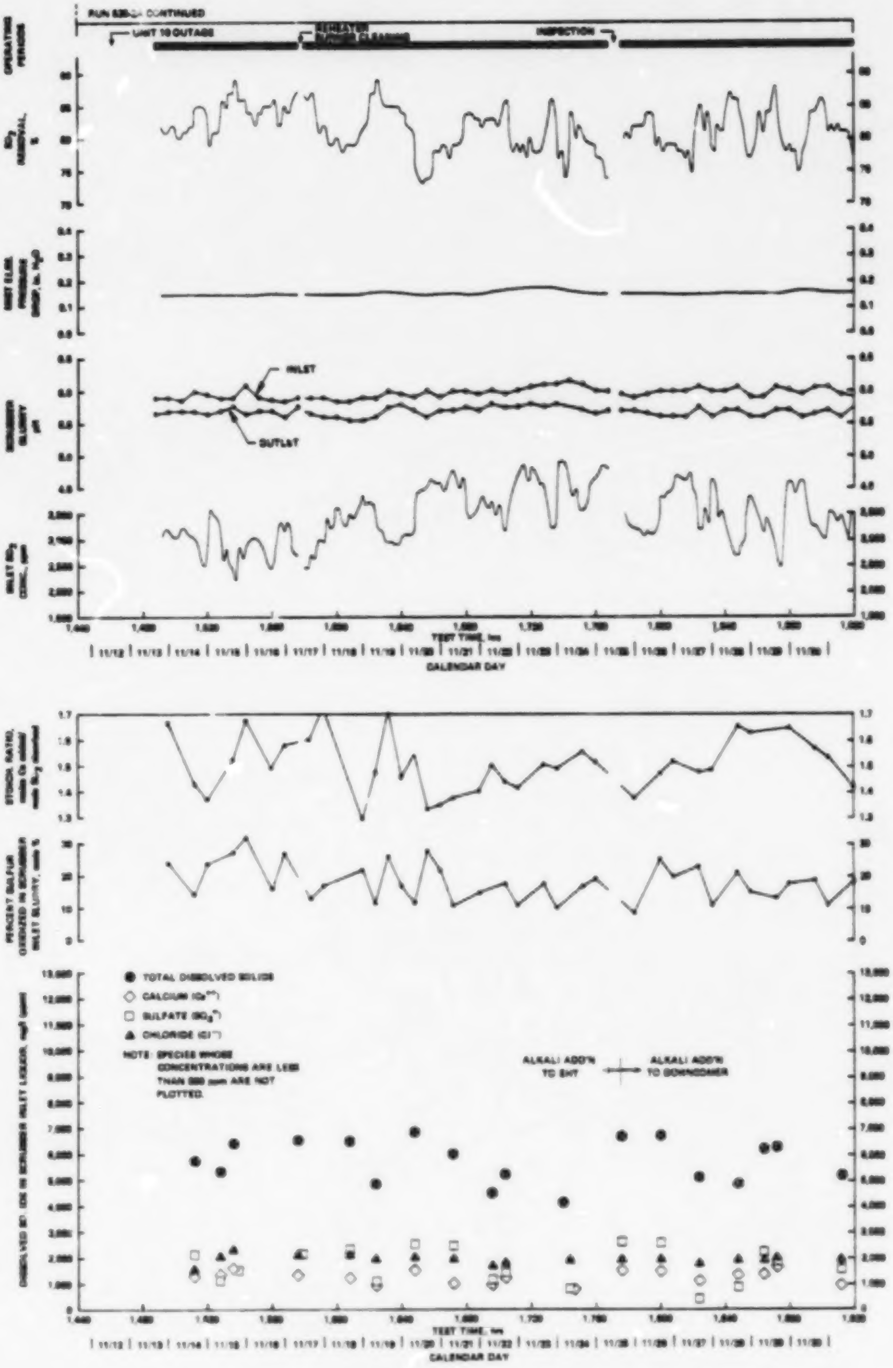
Figure F-1. Operating Data for TCA Run 535-2A (continued)



Gas Rate = 20,530 acfm @ 300° F
Liquor Rate = 1200 gpm
L/G = 73 gal/mcf
Gas Velocity = 8.8 ft/sec
EHT (Sealed) Residence Time = 12 min (9/12-9/27),
    15 min (after 9/27)
Three Stages, 5 in spheres/stage

Percent Solids Recirculated = 12-15 wt %
Total Pressure Drop, Excluding Mist Elim.
    and Koch Tray = 4.0-4.8 in H_2O
Scrubber Inlet Liquor Temperature = 123-128° F
Liquid Conductivity = 4,000-6,100 μ mhos/cm
Discharge (Clarifier) Solids
    Concentration = 35-42 wt %

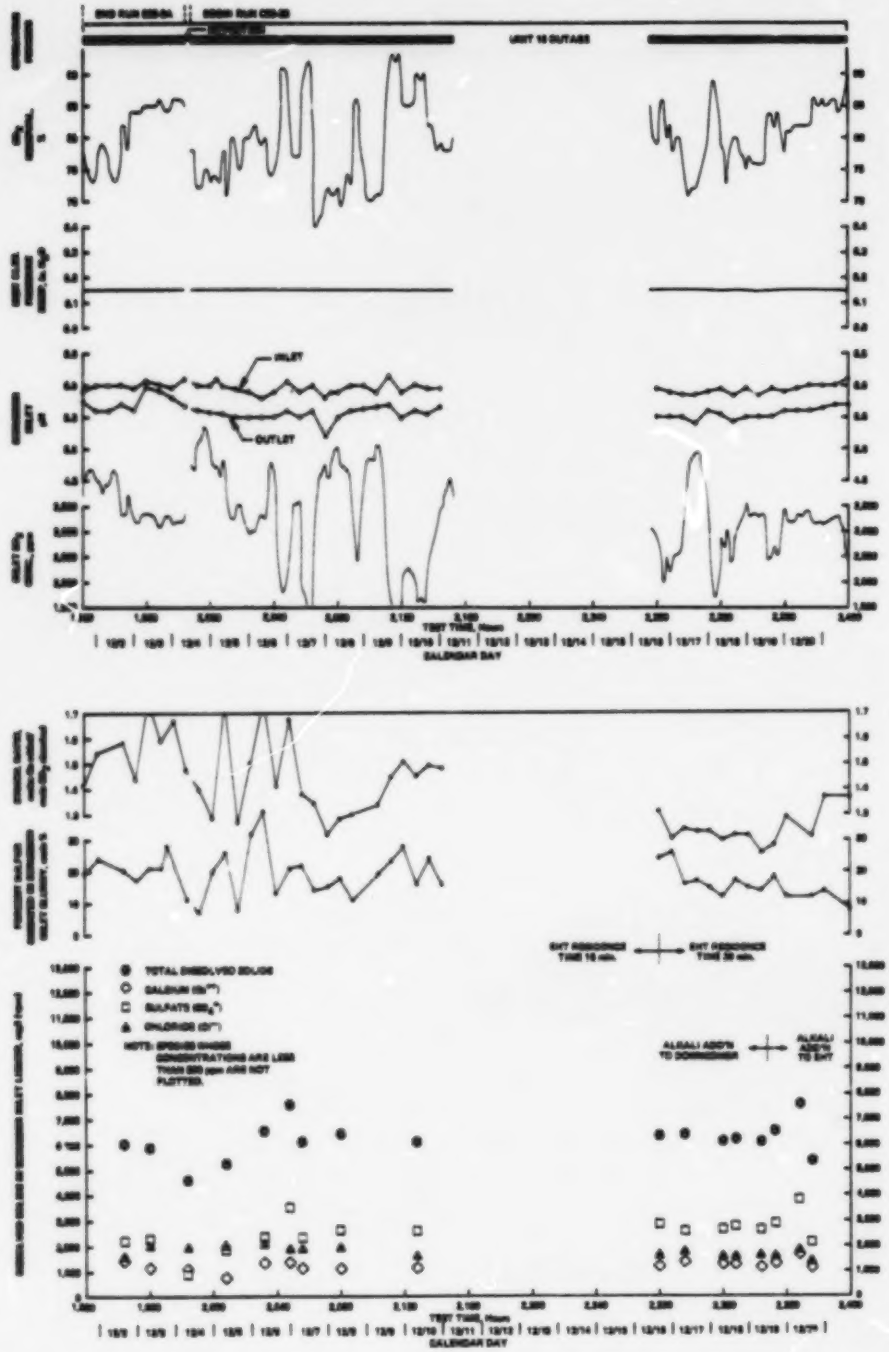
Figure F-1. Operating Data for TCA Run 535-2A (continued)



Gas Rate = 20,900 acfm @ 300° F
Liquor Rate = 1200 gpm
L/G = 73 gal/mcf
Gas Velocity = 8.6 ft/sec
EHT (Sealed) Residence Time = 12 min (8/12-9/27),
15 min (after 9/27)
Three Stages, 5 in spheres/stage

Percent Solids Recirculated = 12-15 wt %
Total Pressure Drop, Excluding Mist Elim.
and Koch Tray = 4.0-4.8 in H_2O
Scrubber Inlet Liquor Temperature = 115-124° F
Liquid Conductivity = 4,500-6,000 μmhos/cm
Discharge (Clarifier) Solids
Concentration = 32-40 wt %
Limestone Addition to EHT (8/12-11/26),
to Downcomer (after 11/26)

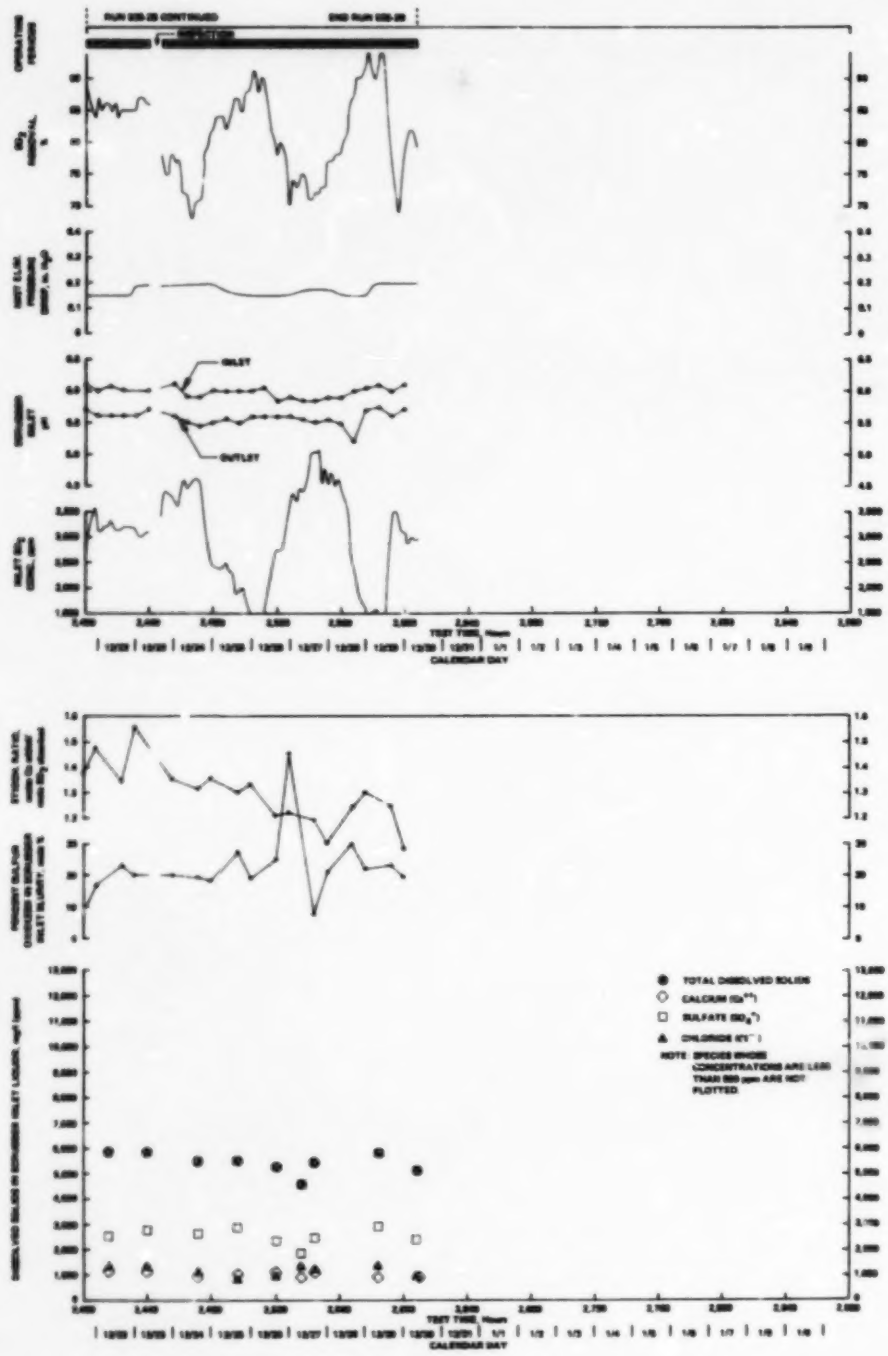
Figure F-1. Operating Data for TCA Run 535-2A (continued)



Gas Rate = 20,500 acfm @ 300 °F
Liquor Rate = 1200 gpm
L/G = 73 gal/mcf
Gas Velocity = 8.6 ft/sec
EHT (Sealed) Residence Time = 15 min (through 12/15),
  20 min (after 12/15)
Three Stages, 5 in spheres/stage

Percent Solids Recirculated = 9-16 wt %
Total Pressure Drop, Excluding Mist Elim.
  and Koch Tray = 3.8-4.8 in H_2O
Scrubber Inlet Liquor Temperature = 119-126 °F
Liquid Conductivity = 3,800-4,800 μ mhos/cm
Discharge (Clarifier) Solids Concentration = 38-42 wt %
Limestone Addition to Downcomer (through 12/19),
  EHT (after 12/19)

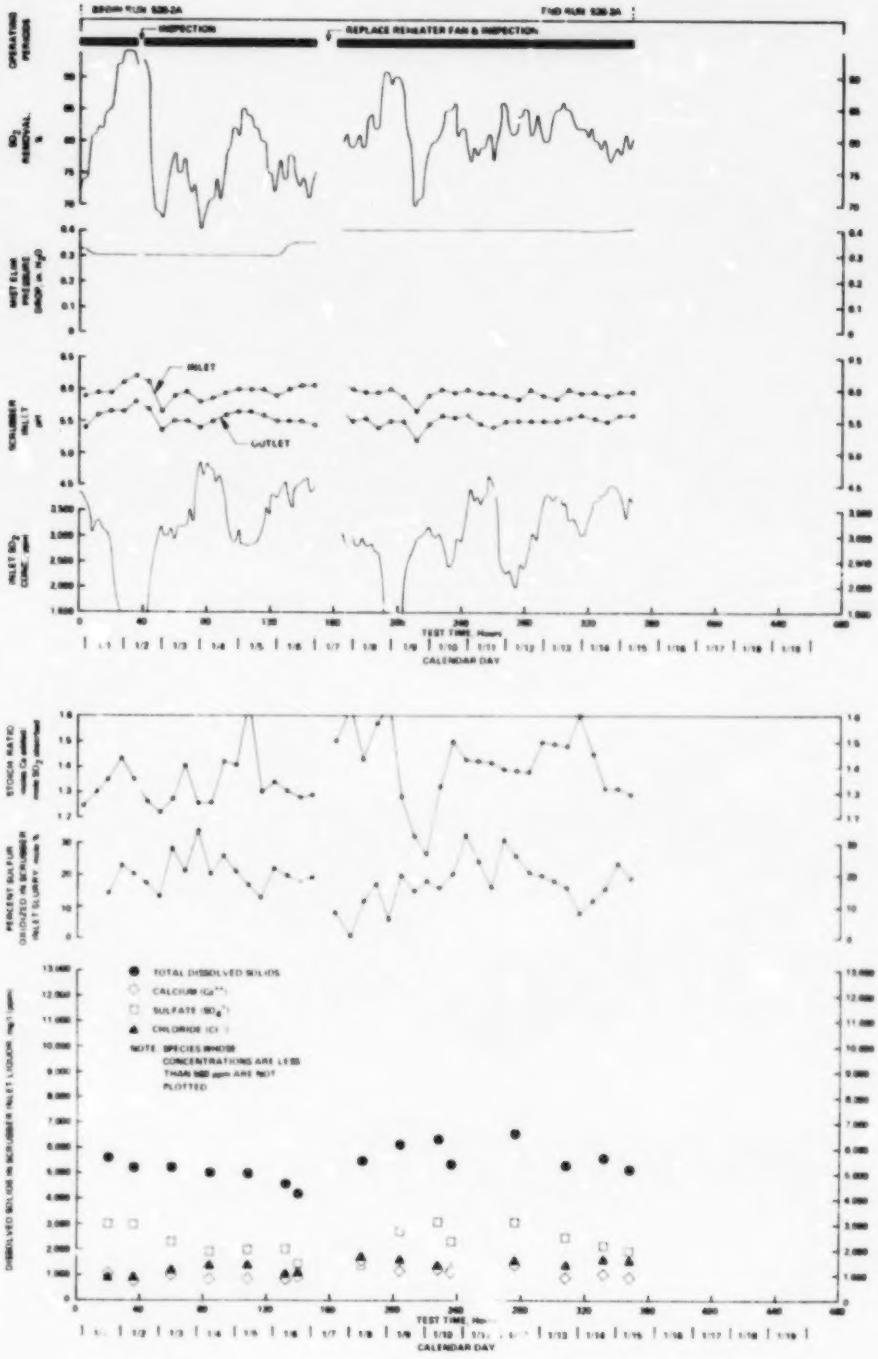
Figure F-2. Operating Data for TCA Run 535-2A & 2B



Gas Rate = 20,500 acfm @ 300 °F
Liquor Rate = 1200 gpm
L/G = 73 gal/mcf
Gas Velocity = 8.6 ft/sec
EHT (Sealed) Residence Time = 15 min (through 12/15), 25 min (after 12/15)
Three Stages, 5 in spheres/stage

Percent Solids Recirculated = 11-15 wt %
Total Pressure Drop, Excluding Mist Elim. and Koch Tray = 4.4-5.0 in H_2O
Scrubber Inlet Liquor Temperature = 118-126 °F
Liquid Conductivity = 3,000-7,000 μ mhos/cm
Discharge (Clarifier) Solids Concentration = 34-41 wt %
Limestone Addition to EHT

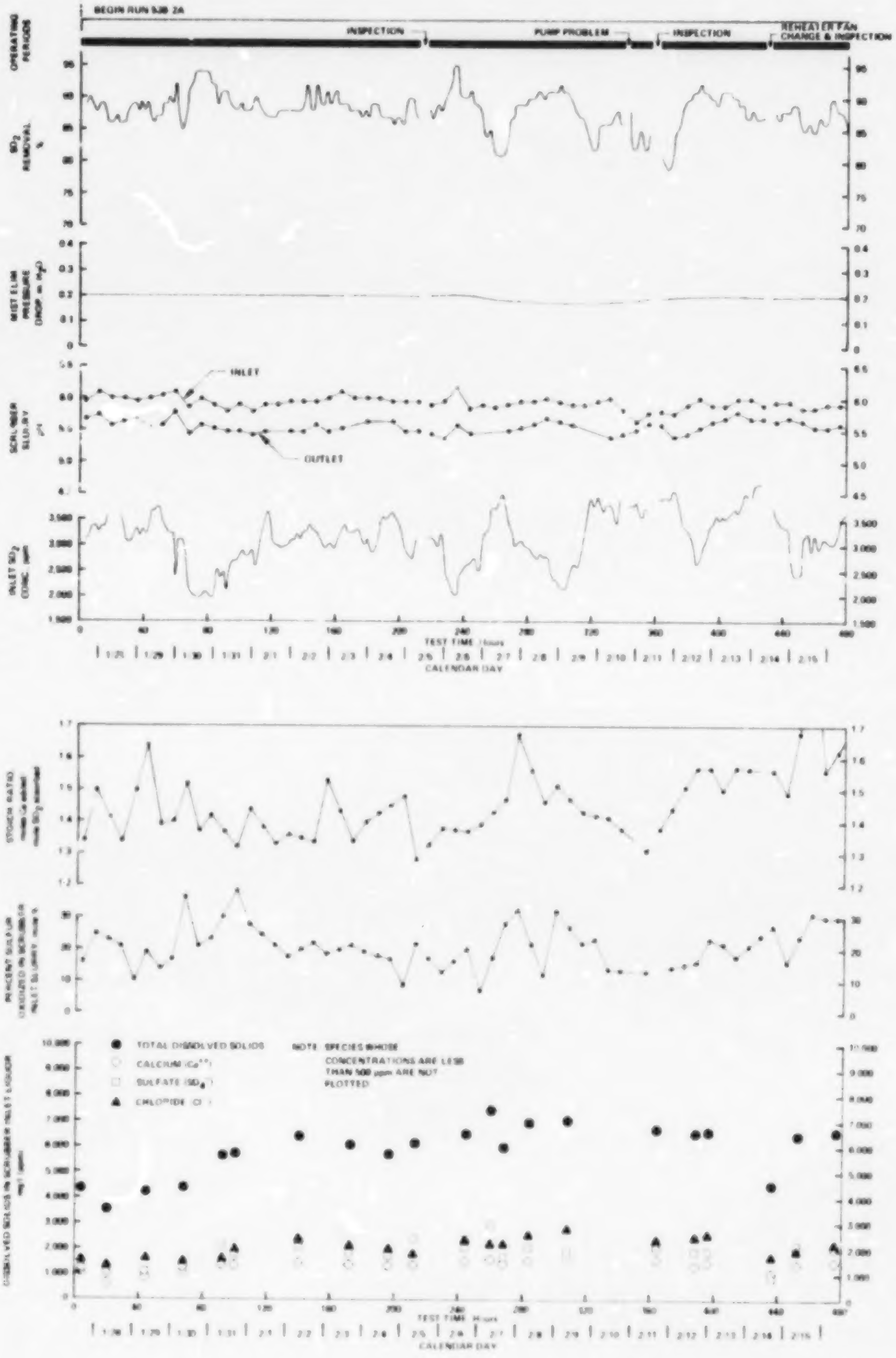
Figure F-2. Operating Data for TCA Run 535-2B (continued)



Gas Rate = 24,000 acfm @ 300 °F
Liquor Rate = 1200 gpm
L/G = 62 gal/mcf
Gas Velocity = 10.0 ft/sec
EHT (Sealed) Residence Time = 20 min
Three Stages, 5 in spheres/stage

Percent Solids Recirculated = 13-16 wt %
Total Pressure Drop, Excluding Mist Eliminator and Koch Tray = 5.2-5.6 in H_2O
Scrubber Inlet Liquor Temperature = 120-127 °F
Liquid Conductivity = 3,300-4,900 μ mhos/cm
Discharge (Clarifier) Solids Concentration = 32-43 wt %
Limestone Addition to EHT

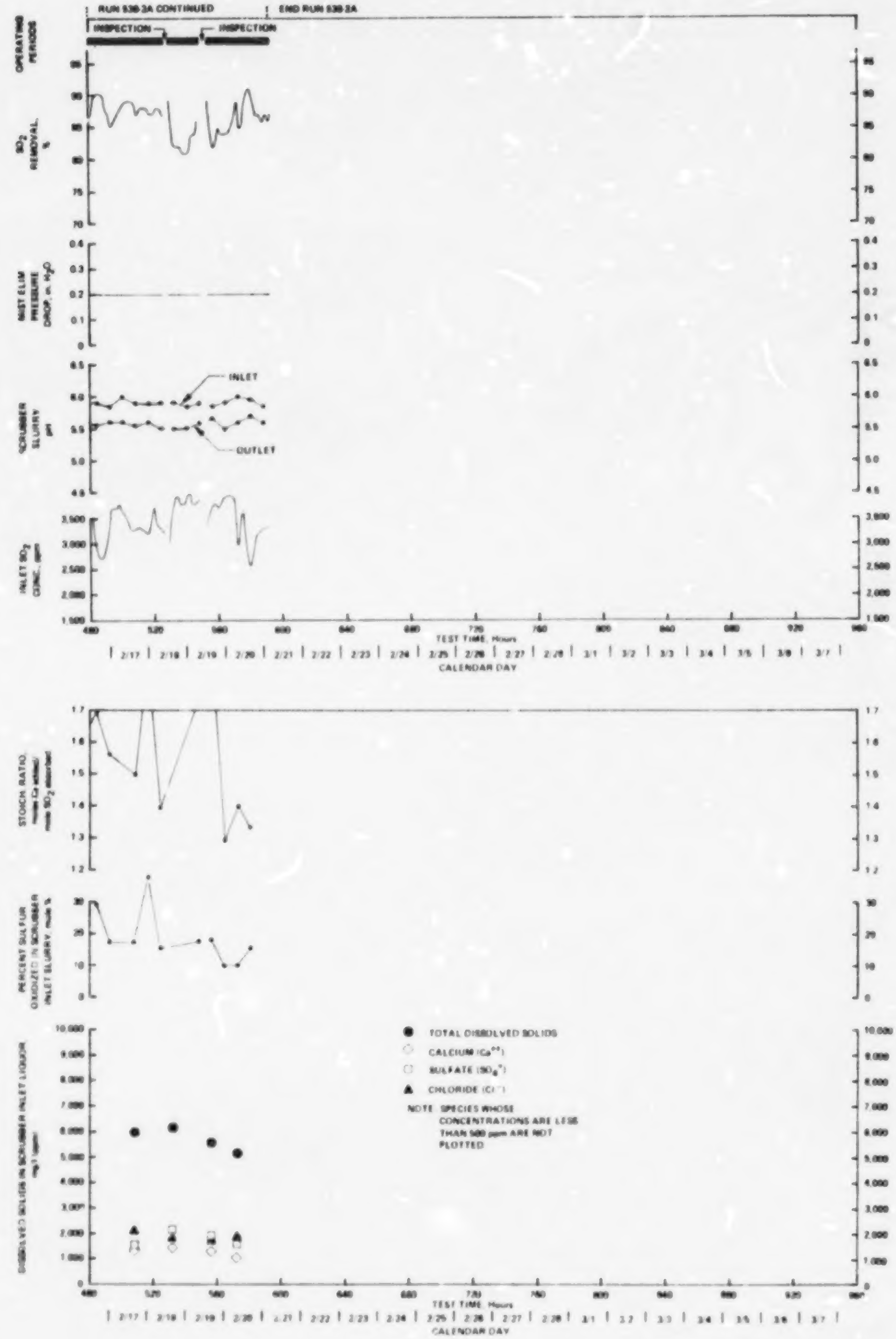
Figure F-3. Operating Data for TCA Run 536-2A



Gas Rate = 24,000 acfm @ 300 °F
Liquor Rate = 1400 gpm
L/G = 73 gal/mcf
Gas Velocity = 10.0 ft/sec
EHT (Sealed) Residence Time = 20 min
Three Stages, 5 in spheres/stage

Percent Solids Recirculated = 13-17 wt %
Total Pressure Drop, Excluding Mist Elim.
and Koch Tray = 5.7-6.7 in H_2O
Scrubber Inlet Liquor Temperature = 118-125 °F
Liquid Conductivity = 3,600-5,500 μ mhos/cm
Discharge (Clarifier) Solids Concentration = 31-38 wt %
Limestone Addition to EHT

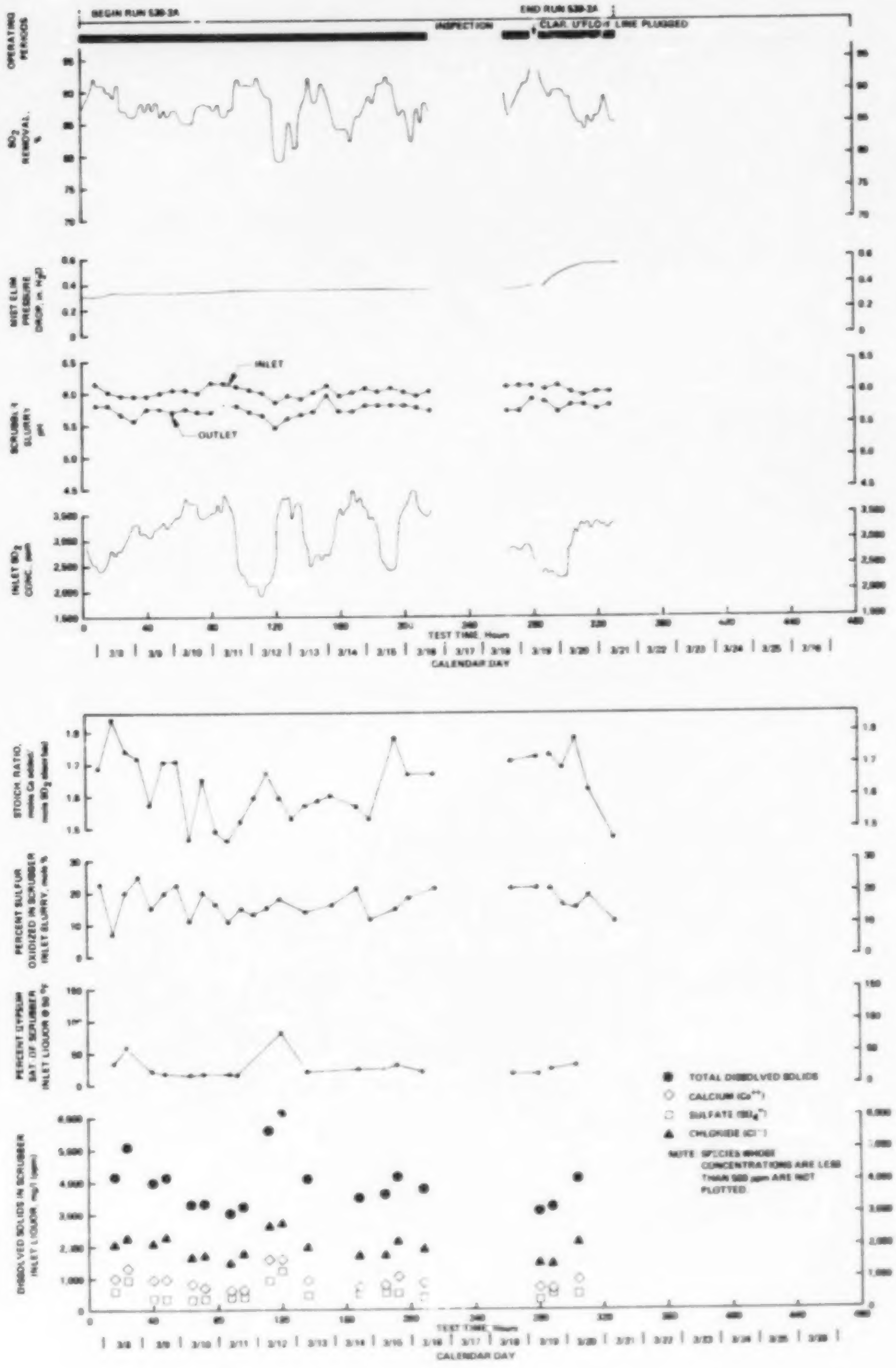
Figure F-4. Operating Data for TCA Run 538-2A



Gas Rate = 24,000 acfm @ 300 °F
Liquor Rate = 1400 gpm
L/G = 73 gal/mcf
Gas Velocity = 10.0 ft/sec
EHT (Sealed) Residence Time = 20 min
Three Stages, 5 in spheres/stage

Percent Solids Recirculated = 15-17 wt %
Total Pressure Drop, Excluding Mist Elim.
and Koch Tray = 6.0-6.8 in H_2O
Scrubber Inlet Liquor Temperature = 120-127 °F
Liquid Conductivity = 3,800-4,900 u mhos/cm
Discharge (Clarifier) Solids Concentration = 33-41 wt %
Limestone Addition to EHT

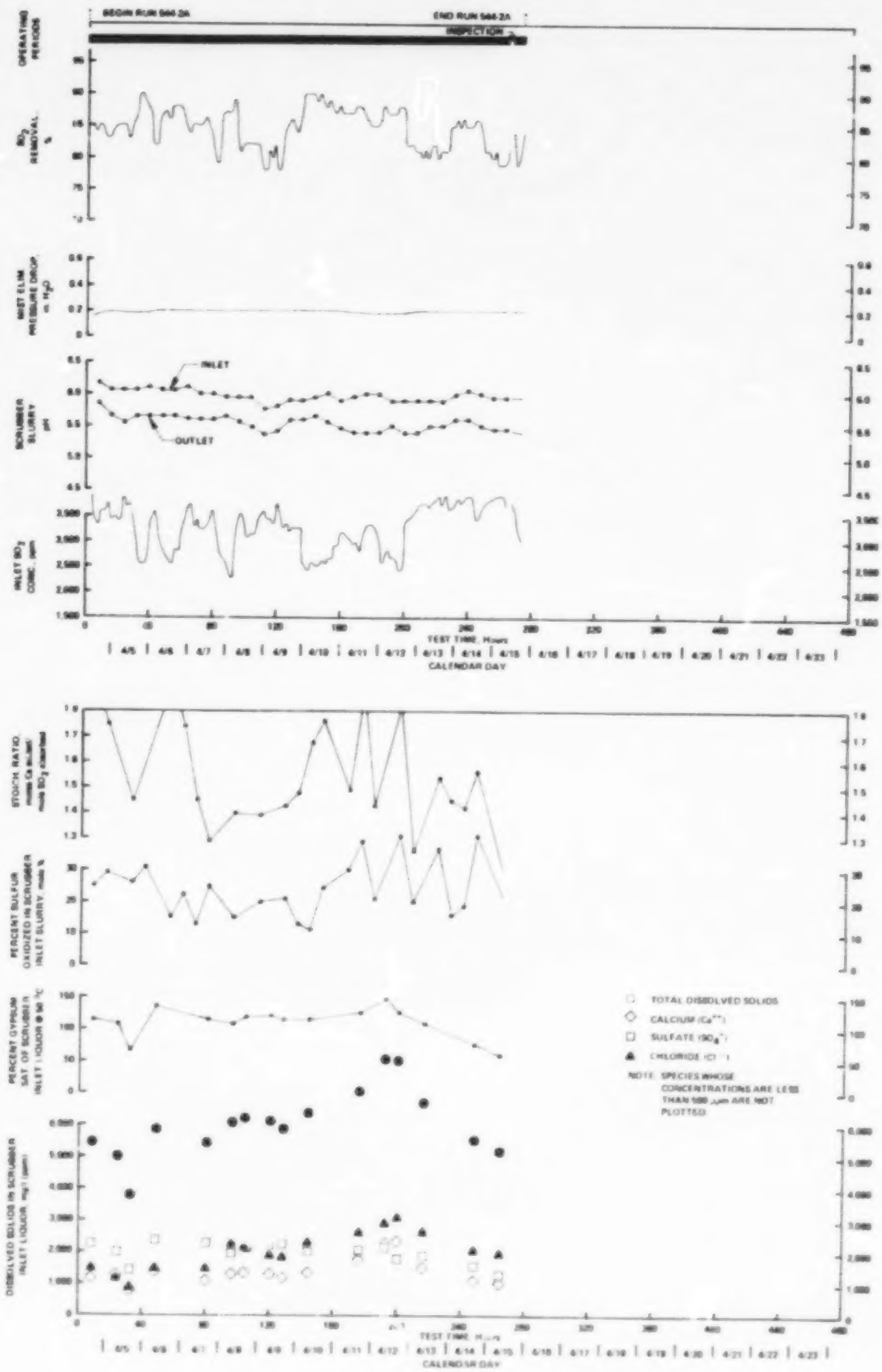
Figure F-4. Operating Data for TCA Run 538-2A (continued)



Gas Rate = 28,000 acfm @ 300 °F
Liquor Rate = 1000 gpm
L/G = 43 gal/mcf
Gas Velocity = 12.8 ft/sec
EHT (Seeco) Residence Time = 25 min
Three Stages, 5 in spheres/stage

Percent Solids Recirculated = 13-17 wt %
Total Pressure Drop, Excluding Mist Elim
and Koch Tray = 6.7-6.85 in H_2O
Scrubber Inlet Liquor Temperature = 120-128 °F
Liquid Conductivity = 3,400-5,100 μ mhos/cm
Discharge (Clarifier) Solids
Concentration = ~ 40 wt %
Limestone Addition to EHT

Figure F-5. Operating Data for TCA 539-2A



Gas Rate = 20,500 acfm @ 300 °F
Liquor Rate = 1200 gpm
L/G = 13 gal/mcf
Gas Velocity = 8.6 ft/sec
EHT (Sealed) Residence Time = 15 min
Three Stages, 5 in spheres/stage

Percent Solids Recirculated = 12.3-15.0 wt %
Total Pressure Drop, Excluding Mist Elim.
and Koch Tray = 5.8-6.7 in H_2O
Scrubber Inlet Liquor Temperature = 120-126 °F
Liquid Conductivity = 3,900-8,700 μ mhos/cm
Discharge (Clarifier) Solids
Concentration = 35-40 wt %
Limestone Addition to EHT

Figure F-6. Operating Data for TCA Run 544-2A

Appendix G

AVERAGE LIQUOR COMPOSITIONS FOR TCA LIMESTONE RELIABILITY TESTS

Table G-1

AVERAGE LIQUOR COMPOSITIONS FOR TCA LIMESTONE RUN 535-2A

Sample Point	pH	Liquor Species Concentrations, mg/l (ppm)									Calculated Percent Sulfate Saturation
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$SO_3^{=}$	$SO_4^{=}$	$CO_3^{=}$	Cl^{-}	Total	
Scrubber Inlet											
9/28-10/23/74	5.95	1800	300	55	70	70	1700	90	3000	7000	115
10/24-12/4/74	5.95	1200	350	50	60	90	1950	125	1850	5700	105
Scrubber Outlet											
9/28-10/23/74	5.40	1600	280	55	65	110	1750	100	2500	6500	115
10/24-12/4/74	5.65	1250	300	50	60	95	1790	170	1950	5700	105
Koch Tray Inlet[b]											
9/28-10/23/74	7.20	1600	300	60	55	40	1800	70	2700	6500	115
10/24-12/4/74	7.10	1230	350	50	60	30	1825	110	1810	5500	100
Koch Tray Outlet[c]											
9/28-10/23/74	5.25	1420	180	35	35	880	1480	5	1760	5795	100
10/24-12/4/74	5.20	1270	210	30	45	1090	1740	35	1150	5570	105

Notes: The values in this table are averages for the steady state operating period.
Solids Disposal System: Clarifier only.
The following ranges of values were observed during the run:
Percent sulfur oxidized: 10-30
Loop closure, percent solids discharged: 32-42

(a) (activity Ca^{++}) x (activity $SO_4^{=}$) / (solubility product at 50°C). Estimated solubility product for $CaSO_4 \cdot 2H_2O$ at 50°C is 2.2×10^{-5} (Radian Corporation, "A Theoretical Description of the Limestone-Injection Wet Scrubbing Process", NAPCA Report, June 9, 1970).

(b) Clarified liquor (undiluted).

(c) Liquor stream consists of 9 gpm of make-up water and 15 gpm of clarified liquor.

Table G-1 (continued)

AVERAGE LIQUOR COMPOSITIONS FOR TCA LIMESTONE RUN 535-2B

Sample Point	pH	Liquor Species Concentrations, mg/l (ppm)									Calculated Percent Sulfate Saturation at 50°C[a]
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$SO_3^{=}$	$SO_4^{=}$	$CO_3^{=}$	Cl^{-}	Total	
Scrubber Inlet	5.95	1130	410	40	65	105	2550	110	1510	5900	125
Scrubber Outlet	5.50	1120	390	40	75	230	2600	80	1610	5900	125
Koch Tray Inlet[b]	7.30	1120	390	45	70	40	2560	100	1440	5900	120

Notes: The values in this table are averages for the steady state operating period.
Solids Disposal System: Clarifier only.
The following ranges of values were observed during the run:
Percent sulfur oxidized: 10-30
Loop closure, percent solids discharged: 34-42

(a) (activity Ca^{++}) x (activity $SO_4^{=}$) / (solubility product at 50°C). Estimated solubility product for $CaSO_4 \cdot 2H_2O$ at 50°C is 2.2×10^{-5} (Radian Corporation, "A Theoretical Description of the Limestone-Injection Wet Scrubbing Process", NAPCA Report, June 9, 1970).

(b) Bottom of mist eliminator washed with 9 gpm make-up water plus 6 gpm clarified liquor. Koch tray irrigated with 9 gpm clarified liquor plus 15 gpm mist elimin[illegible]h (24 gpm total).

Table G-1 (continued)

AVERAGE LIQUOR COMPOSITIONS FOR TCA LIMESTONE RUN 536-2A

Sample Point	pH	Liquor Species Concentrations, mg/l (ppm)									Calculated Percent Sulfate Saturation at 50°C[(a)]
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$SO_3^{=}$	$SO_4^{=}$	$CO_3^{=}$	Cl^{-}	Total	
Scrubber Inlet	5.95	950	400	40	40	110	2300	200	1500	5540	100
Scrubber Outlet	5.55	1000	430	40	55	110	2350	140	1200	5490	105
Koch Tray Inlet[(b)]	7.2	1020	400	40	60	65	2600	100	1150	5430	115
Koch Tray Outlet	5.3	1100	250	30	40	1150	2300	20	850	5740	120

Notes: The values in this table are averages for the steady state operating period.
Solids Disposal System: Clarifier only.
The following ranges of values were observed during the run:
Percent sulfur oxidized: 6-30
Loop closure, percent solids discharged: 32-43

(a) (activity Ca^{++}) x (activity $SO_4^{=}$) / (solubility product at 50°C). Estimated solubility product for $CaSO_4 \cdot \frac{1}{2}H_2O$ at 50°C is 2.2×10^{-5} (Radian Corporation, "A Theoretical Description of the Limestone-Injection Wet Scrubbing Process", NAPCA Report, June 9, 1970).

(b) Bottom of mist eliminator washed continuously with constant 15 gpm (17 gpm after 1/10) diluted clarified liquor (all makeup plus necessary clarified liquor). Koch tray irrigated with remaining clarified liquor. Minimum clarified liquor return 15 gpm (20 gpm after 1/7).

Table G-1 (continued)

AVERAGE LIQUOR COMPOSITIONS FOR TCA LIMESTONE RUN 538-2A

Sample Point	pH	Liquor Species Concentrations, mg/l (ppm)									Calculated Percent Sulfate Saturation at 50°C[(a)]
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$SO_3^{=}$	$SO_4^{=}$	$CO_3^{=}$	Cl^{-}	Total	
Scrubber Inlet	5.90	1330	350	50	55	110	1820	160	2010	5900	100
Scrubber Outlet	5.55	1370	340	45	45	170	1750	190	1900	5800	100
Koch Tray Inlet[(b)]	7.35	1310	320	40	50	30	1950	140	1880	5700	110
Koch Tray Outlet	5.55	1270	220	35	40	840	1850	45	1280	5600	110

Notes: The values in this table are averages for the steady state operating period.
Solids Disposal System: Clarifier only.
The following ranges of values were observed during the run:
Percent sulfur oxidized: 10-30
Loop closure, percent solids discharged: 31-40

(a) (activity Ca^{++}) x (activity $SO_4^{=}$)/(solubility product at 50°C). Estimated solubility product for $CaSO_4 \cdot 2H_2O$ at 50°C is 2.2 x $10^{-[illegible]}$ (Radian Corporation, "A Theoretical Description of the Limestone-Injection Wet Scrubbing Process". NAPCA Report, June 9, 1970).

(b) Bottom of mist eliminator washed continuously with constant 20 gpm diluted clarifier liquor (all makeup plus necessary clarified liquor). Koch tray irrigated with remaining clarified liquor. Minimum clarified liquor return 17 gpm.

Table G-1 (continued)

AVERAGE LIQUOR COMPOSITIONS FOR TCA LIMESTONE RUN 539-2A

Sample Point	pH	Liquor Specie Concentrations, mg/l (ppm)									Calculated Percent Sulfate Saturation at 50°C[(a)]
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$SO_3^{=}$	$SO_4^{=}$	$CO_3^{=}$	Cl^{-}	Total	
Scrubber Inlet	6.00	840	280	35	40	75	550	140	1940	3900	25
Scrubber Outlet	5.75	940	270	35	40	80	620	170	2130	4300	35
Koch Tray Inlet[(b)]	7.65	990	250	30	35	20	750	85	1860	4000	45
Koch Tray Outlet	5.70	880	170	20	25	530	780	70	1170	3600	45

Notes: The values in this table are averages for the steady state operating period.
Solids Disposal System: Clarifier and Filter.
The following ranges of values were observed during the run:
Percent sulfur oxidized: 10-22
Loop closure percent solids discharged: ~ 40

(a) (activity Ca^{++}) x (activity $SO_4^{=}$)/(solubility product at 50°C). Estimated solubility product for $CaSO_4 \cdot 2H_2O$ at 50°C is 2.2×10^{-5} (Radian Corporation, "A Theoretical Description of the Limestone-Injection Wet Scrubbing Process", NAPCA Report, June 9, 1970).

(b) Bottom of mist eliminator washed continuously with constant 25 gpm diluted clarifier liquor (all makeup plus necessary clarified liquor). Koch tray irrigated with remaining clarified liquor. Minimum clarified liquor return 22 gpm.

Table G-1 (continued)

AVERAGE LIQUOR COMPOSITIONS FOR TCA LIMESTONE RUN 544-2A

Sample Point	pH	Liquor Species Concentraions, mg/l (ppm)									Calculated Percent Sulfate Saturation at 50°C(a)
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$SO_3^{=}$	$SO_4^{=}$	$CO_3^{=}$	Cl^{-}	Total	
Scrubber Inlet	5.95	1400	350	40	50	100	1980	95	2010	6000	110
Scrubber Outlet	5.50	1300	370	40	50	150	1980	115	1990	5900	110
Koch Tray Inlet(b)	7.20	1230	380	35	50	90	1800	70	1990	5600	95
Koch Tray Outlet	5.40	1380	220	30	30	1080	1870	9	1280	5900	115

Notes: The values in this table are averages for the steady state operating period.
Solids Disposal System: Clarifier
The following ranges of values were observed during the run:
Percent sulfur oxidized: 12-40
Loop closure, percent solids discharged: 35-40

(a) (activity Ca^{++}) x (activity $SO_4^{=}$)/(solubility product at 50°C). Estimated solubility product for $CaSO_4 \cdot 2H_2O$ at 50°C is 2.2×10^{-5} (Radian Corporation, "A Theoretical Description of the Limestone-Injection Wet Scrubbing Process", NAPCA Report, June 9, 1970.

(b) Bottom of mist eliminator washed continuously with 15 to 19 gpm diluted clarifier liquor (all makeup plus necessary clarified liquor). Koch tray irrigated with remaining clarified liquor. Minimum clarified liquor return 15 gpm.

Appendix H

DEFINITION OF STATISTICAL TERMS

The fraction of variation that is explained by a correlation is equal to R^2, where R is the correlation coefficient. Thus:*

$$\text{Fraction of Variation Explained} = R^2 = 1 - \frac{\Sigma(y-y')^2}{\Sigma(y-\bar{y})^2} \qquad \text{(H-1)}$$

where:

y = value of the independent variable for a particular data point

y' = predicted (correlation) value of the independent variable for the same data point

$\bar{y}$ = arithmetic average of all values of the independent variable in the correlated set of data

The standard error of estimate is determined from the following equation:**

$$\text{Standard Error of Estimate} = \sqrt{\frac{\Sigma(y-y')^2}{n-k-1}} \qquad \text{(H-2)}$$

where:

n = number of data points in the correlated set of data

k = number of dependent variables fitted with coefficients

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[*] E. L. Crow, et al., "Statistics Manual," chapter 6, page 175, Dover, New York, 1960.

[**] Ibid., page 174.